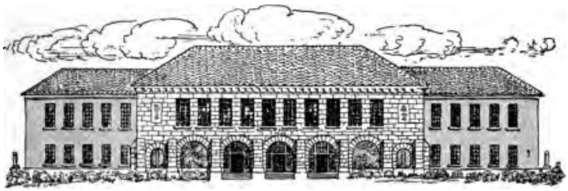
A LABORATORY GUIDE

TO ACCOMPANY

CARHART AND CHUTE'S

FIRST PRINCIPLES OF PHYSICS

ALLYN AND BACON



A LABORATORY GUIDE

TO ACCOMPANY

CARHART AND CHUTE'S FIRST PRINCIPLES OF PHYSICS

BY

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No phenomenon is fully understood unless it can be described in terms of magnitudes which have been measured exactly.

— EDWIN EDSER.

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PREFACE

THE purpose of the laboratory study of Physics is not one of discovery, neither is it one of verification of physical laws. Most physical truths, tested by the laboratory evidence gathered by the average beginner, would be judged as false. Some reason must be found for the laboratory's existence other than that of the "student's reading Nature in the light of experiment." Its right to exist is to be found rather in its effectiveness in cultivating right habits of work, in its demand for system, care, and accuracy on the part of the pupil.

The value of the laboratory must depend in no small measure on the character of the problems proposed, as well as on the manner of solving them. Not many qualitative exercises are adapted to securing the results mentioned above, and many quantitive ones involve skill beyond the reach of the beginner. Still others fail to interest him because of their uselessness as he sees it, or because of their wearisome details.

In this *Guide* it has been the author's aim to choose such problems as his experience has shown to be within the range of the beginner's skill. They are not so tedious as to wear out the pupil's interest, nor so difficult as to discourage him, nor are they of such a character as to demand apparatus beyond the pocketbook of the school. The problems presented have been found to interest boys and girls alike, and the methods presented have in their hands yielded satisfactory results. These problems also illustrate many of the methods of modern Physics, the processes by which the science has grown to its present splendid attainments.

The aûthor has placed much stress upon the notebook, what it should be if it is to be worth while. He is convinced that it is through the notebook that many of the greatest benefits come to the student from the study of Physics. Too much emphasis cannot be placed on its accuracy, its completeness, its systematic arrangement, and its mechanical neatness. A slovenly notebook should never be countenanced, and only the best that the student can do should ever be accepted.

The forms of apparatus selected throughout these seventy exercises are such as the experience of several years has shown to be durable and reliable. They are moderate in price and at the same time commendable in appearance, a point not to be overlooked, if physics is to be made attractive. Cheap apparatus is usually a synonym for worthlessness, its chief office being to discourage the not overzealous and disgust those desirous to learn.

Special attention has been given to the illustrations. Wherever possible they are made to picture the experiment and eliminate tedious description. They are in many cases made from photographs of the apparatus as set up for use.

This *Guide* is designed to accompany Carhart and Chute's *First Principles of Physics*, and consequently frequent references are made to that book throughout its pages.

Such tables of constants are appended as the exercises require, either for comparison or for use in calculations.

H. N. C.

ANN ARBOR,
July, 1913.

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A LABORATORY GUIDE IN PHYSICS

INTRODUCTION

1. To the Student. — Read carefully each assigned exercise, note the steps taken, their purpose, and their order. Study the plan of the apparatus, the manner of using it, and the purpose of each adjustment. It is important to fix in the memory the succession of the steps to be taken in the experiment; to interrupt the work to consult directions may cause you to miss seeing the phenomenon that the experiment is designed to develop.

Before reporting for work in the laboratory, the notebook should be made ready as described in § 2. All observations should be recorded exactly as seen, and all scale readings exactly as read from the instrument; the reductions of these quantities to other forms should be made a separate entry.

No work should ever be erased; if found to be wrong, inclose it in brackets, thus, [—]. Records should never be made on loose papers, but should always be made first hand in the notebook, so that the notebook may contain the original entries. Records should never be taken from the laboratory until they are completed; and not then, without leaving with the instructor a proofread copy of the observations made. Record things *just as you see them and not as you think they ought to be.* Plan your work beforehand so as to save time; frequently two operations can be carried on simultaneously.

2. The Temporary Notebook. — This is the notebook of the laboratory and may be made the general notebook for all the

student's classes. It should be of loose leaves, about 6 in. × 8 in. in size, having a substantial cover with a place for the student's name on the outside, and composed of paper of good quality half ruled and half unruled. All entries should be made with a lead pencil, using preferably one of the grade No. 3.

After the student has carefully studied the assigned problem, he should prepare his notebook for the work after the following plan:

Two pages or one leaf are to be given to a problem.

At the top of the first page write the *Number* and the *Statement* of the problem.

Leave a blank space of two lines to be used later in writing the *Special Statement.* To illustrate: —

Exercise 1. The Linear Scale.

Special Statement. — Determine the ratio of the length of laboratory table No. 4 to its width.

Follow this with a paragraph headed, *Apparatus,* and give under this a list of the appliances used, placing parentheses after each name, thus, (—), within which enter the number of the piece as soon as known.

Mark the next paragraph *Results,* and follow it by a ruled form for tabulating the observations. When sketches of the apparatus are required, these are to be made on the reverse side. Also place on the reverse side any notes taken, to be used subsequently in preparing a discussion of the problem.

After all the needed data are secured the work should be submitted to the instructor for approval before work on a new problem is begun.

3. The Permanent Notebook. — In this book the leaves are not removable, the binding is substantial, the paper is "squared paper," metric ruling, and all entries are made in ink with the possible exception of drawings. Mechanical execution receives more attention in this book, and the tabulation of all data must be made to square with the ruling. The data are a copy of

those found in the temporary notebook, and the drawings are carefully made.

4. The Weekly Report. — The writing up of the work each week in the permanent notebook after the following plan constitutes the *Weekly Report*. In general, each problem will require three pages, rarely more than four. At the *top of the first* of these write the *Number* and the *Subject*, followed by the *Special Statement*. About *six lines* from the top write *Apparatus*, giving a list of pieces used, the identification numbers, and a drawing in pencil of the principal pieces or a sketch of the apparatus as set up. These drawings should emphasize the plan of the instrument, and should be reasonably accurate. On the *fifth line* from the bottom of the page write *References*. Under this heading state where the problem is found and the titles of books used in preparing the report. At the *top of the second page*, under the heading *Results*, copy accurately the tabular record of the observations and measurements as found in the *Temporary Notebook*. Toward the *bottom of this page*, under *Calculations*, show all the more important mathematical operations that have entered into the work. The conclusions reached by these calculations should be placed in the tabular scheme. The *third page* is devoted to the *Discussion* of the results, and in some instances it may be necessary to give two pages to this important feature. For this reason it is imperative that the discussion of a problem should be written before starting to write up the succeeding problem, in order to determine the space necessary for it. In the case of a few problems it will be necessary to devote the third page to a *Graph* (5),* representing the data. The problem then should be begun on the right-hand page, so that the graph may face the data; the discussion will appear on the fourth page. In writing the headings it will greatly improve the appearance of the book if they are executed in some form of heavy letter. This offers

* Figures within parentheses refer to sections of this book.

an excellent opportunity for the student to learn to make some form of printed or fancy letter.

The *Discussion* should be written at home. It should be carefully done both from an English and from a scientific point of view. It should be written in ink, on note paper, about 5 in. × 8 in., and laid in the notebook by the page reserved for it. After the instructor has examined it, the student should correct any defects marked and then copy it into the notebook. The discussion should state the character of the errors that enter into the work, should state what measures were taken to reduce or eliminate errors, and should point out what the work shows regarding the subject under consideration.

5. The Graph is a very efficient way to make clear the relation that may exist between two quantities or variables; as, for example, the volume of a gas and the pressure it is under. The shape of the curve may indicate the form of the law; as, for example, a straight line would imply that one quantity varies directly as the other.

In the graphic representation of data it is necessary to use cross-section paper. In doing so, select a scale for the work such as will confine the curve to the page, and, at the same time, practically cover it. In general, the starting point of the horizontal scale, the *Origin*, as well as that of the vertical one, will be the corner of some one square near the lower left-hand corner of the page. There will be times, however, as in Fig. 1, when it is advisable to place the origin off the page. The horizontal line through the origin is called the *Axis of X*, and the vertical one, the *Axis of Y*. Measurements on the *X-axis* are called *Abscissæ*, those on the *Y-axis*, *Ordinates*. The scale for the *X*-measurements and that for the *Y*-measurements must be written along adjacent edges of the page. Positive quantities are measured to the right or upward from the origin, and negative quantities in the opposite direction.

To illustrate the method, let us assume the following data: —

Volume of Air v		Pressure p	Volume of Air v		Pressure p
	$cm.^3$	cm.		$cm.^3$	cm.
a	13.7	104.2	*f*	20.0	71.9
b	14.7	97.2	*g*	21.6	65.3
c	15.9	90.4	*h*	23.5	60.2
d	17.0	83.5	*i*	24.4	57.7
e	19.1	73.7	*k*	25.6	55.4

In order that the curve may occupy the central part of the page the scale for volumes begins at 10 and each centimeter represents 2 $cm.^2$ and each subdivision 0.4 $cm.^3$ The scale for pressure begins at 50, each centimeter represents 5 cm. and each subdivision 1 cm. To locate the point *a*, proceed along the horizontal scale to 13.7, as nearly as can be determined, then pass vertically upward to 104.2, as given by the vertical scale. Mark this point by an × of the size shown (Fig. 1), the center of the × being the point. Each point is located in like manner.

To draw a smooth curve through these points an architect's curved ruler is necessary to get a good result. In the absence of such an instrument transfer these points to a sheet of stiff paper, by pricking through these points with a needle into the stiff paper placed beneath. Then sketch a curve through points as transferred, carefully smoothing out irregularities with a pencil. Such a line may not pass through all the points. With a pair of stout scissors cut the stiff paper along this curve and use the curved edge as a ruler in tracing a smooth heavy line through the points on the cross-section paper.

6. Arithmetical Hints. — Never carry out numbers beyond the first doubtful figure. The accuracy of a result is in no wise increased by a long array of figures following the decimal

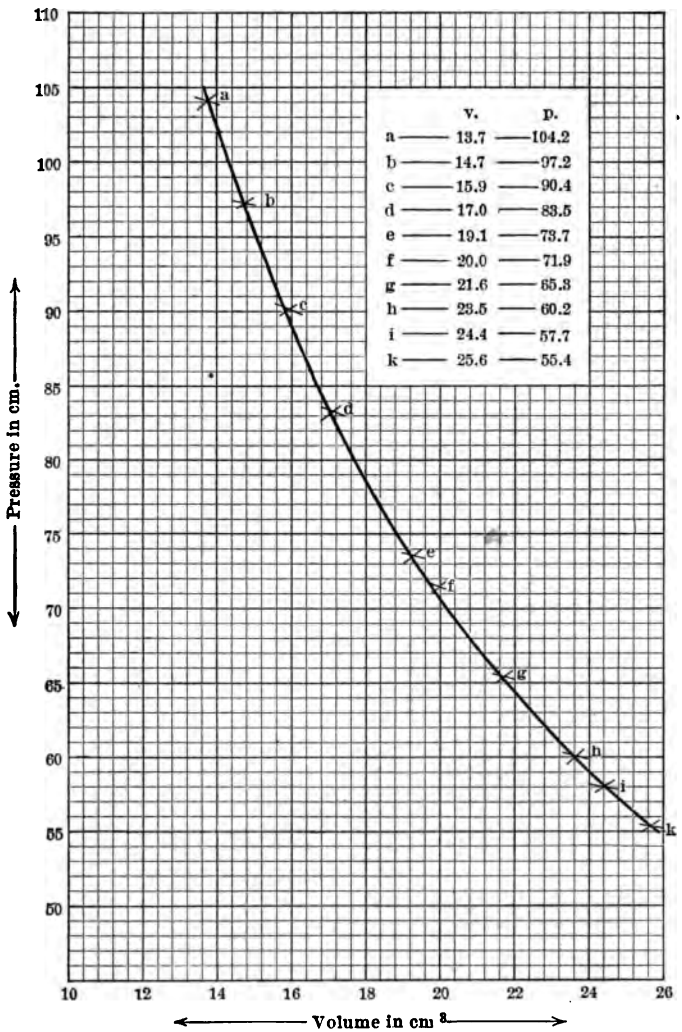

v. p.
a — 13.7 — 104.2
b — 14.7 — 97.2
c — 15.9 — 90.4
d — 17.0 — 83.5
e — 19.1 — 73.7
f — 20.0 — 71.9
g — 21.6 — 65.3
h — 23.5 — 60.2
i — 24.4 — 57.7
k — 25.6 — 55.4
110
105
100
95
90
85
80
75
70
65
60
55
50
10
12
14
16
18
20
22
24
26
Pressure in cm.
Volume in cm³

Fig. 1

point. The probable correctness of the calculation can usually be determined by estimating the reasonableness of the result. The majority of errors are made in locating the decimal point. These can be eliminated by the exercise of a little good sense. In dropping needless decimals always increase by one the last figure retained, if the part dropped is more than 5; if just 5 or less, do not add one.

In the operations of multiplication and division much time is wasted in carrying out results to an absurd number of decimal places. In reading scales of any kind the last figure of the reading is usually an estimated one and consequently is of doubtful accuracy. To extend a result beyond this doubtful figure is useless. Every figure of a product obtained by multiplying by a doubtful figure is doubtful and hence valueless. For example, let us multiply 3.5**6** by 8.4**5**, where **6** and **5** are estimated quantities and hence doubtful. The full calculation is as follows: —

3.5**6**
8.4**5**
17 80
1 42 **4**
28 **48**
30.**08 20**

It appears that the first decimal figure is doubtful. Then all the figures after 0 are to be dropped and the product to be used is 30.1.

This product may be obtained without the introduction of these worthless figures by proceeding as follows: —

3.5**6**
5 48
28 48
1 42
18
30.08

Beneath the multiplicand write the multiplier with the figures in reverse order. Then form the partial products in the ordinary way, always beginning by multiplying each figure into the one above it, increasing the product by the number that would be carried over if the product into the next figure to the right had been found.

A study of the example shows that the abbreviated method yields all the figures that are worth while with a saving of over 30 per cent in the number of figures used.

A like abbreviation of the work is possible in division. An examination of the following example will reveal the method. Let it be required to divide 76.314 by 3.257.

3.257)76.314(23.43	3.257)76.314(23.43
65 14	65 14
11 174	11 17
9 771	9 77
1 4030	1 40
1 3028	1 30
10020	10
9771	10
249	0

The process is shortened by omitting to bring down a new figure for each partial division and offsetting it by dropping one figure of the divisor in forming each partial product.

CHAPTER I

SIMPLE MEASUREMENTS

EXERCISE I. THE LINEAR SCALE

Problem. — *Determine to two decimal places the ratio of the length of one of the laboratory tables to its width.*

Apparatus. — A **meter stick** (Fig. 2), or some form of linear scale, decimally divided; a **carpenter's try-square** (Fig. 3).

Directions. — Figure 4 shows the manner of using the try-square to mark the edge of the table, and also the proper posi-

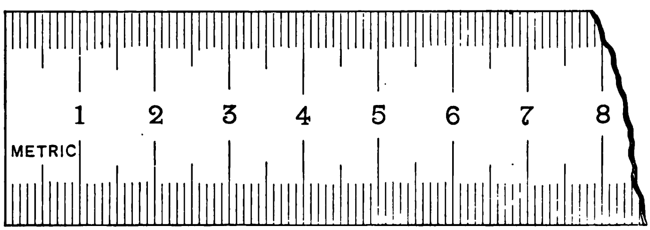


Fig. 2

tion of the meter stick. If the meter stick is placed on the table as shown in Fig. 5, one cannot determine accurately the point on the table that any particular scale division marks, because shifting the position of the eye changes the reading. If the table is longer than the meter stick, it will be necessary to mark on the table where the end of the meter stick is; or,

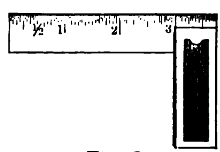


Fig. 3

preferably, where division 90 is, on account of the difficulty of marking exactly where the end is.

To do this without marking the table, place under the meter stick a sheet of white paper on which you have drawn a straight

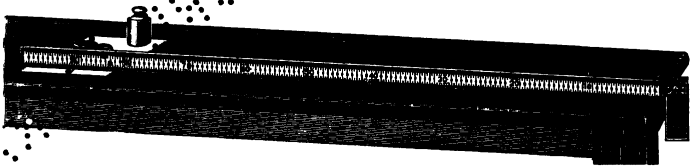


Fig. 4

line, and move it until the line is at right angles to the stick and coincides with the division on the stick that was selected. Hold the paper in place by a weight. Now slide the stick along until division 10 coincides with the mark. Use a small magnifier (Fig. 6) in making such adjustments. Also be sure that this new position of the meter stick is in a straight line with the first position and that both are parallel to the edge of the table. Find some simple way of doing this. Mark the 90th division as before.

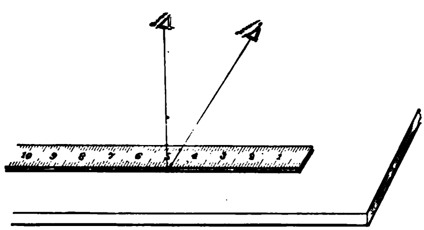


Fig. 5

Continue in this way until the other end of the table is reached. In this last position the meter stick will probably project beyond the edge of the table, and it will be difficult to measure up to the edge. Instead of doing this, use the try-square to locate the edge and then measure back to the line

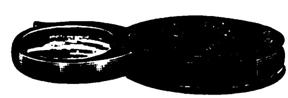


Fig. 6

on the paper. If a division line on the meter stick does not coincide with the line on the paper, estimate with the eye the number of tenths of a millimeter between the line and the scale divisions. Combine carefully all of these quantities, and the number will be the length to record in the notebook

Repeat the work by starting from the other end of the table. The average of these two measurements may be taken as the length of the table, unless they differ by several millimeters. In that case it is evident that a mistake has been made, and that the work should be repeated.

Measure the width by proceeding in a similar manner.

Divide the length by the width, expressing the result to two decimal places. If the third decimal figure would be 5, and the division does not terminate, or if it would be more than 5, then increase the second by one (6).

There are certain errors that cannot be avoided that enter into work, and there are also errors that will be small for careful students and large for careless ones. A consideration of the following questions will make this clear. (*a*) Why place the meter stick on its edge? (*b*) Why must the paper on which the index line is drawn be weighted down? (*c*) Why not make readings to the end of the meter stick instead of to a division near the end? (*d*) Why must the line of measurement be straight and parallel to the edge of the table? (*e*) The scale on a meter stick was stamped on it with a steel die when the stick was straight. What effect would it have on the accuracy of the measurements to make them with a warped meter stick? (*f*) Eye measurements are judgments. Are they accurate?

These questions should be considered before making any measurements, and with a right-minded student they will bear fruit in greater accuracy. Furthermore, such questions as these suggest some of the points to be considered in the discussion.

Form of Tabulation. — Record the measurements as in the following example: —

DIMENSIONS OF LABORATORY TABLE NO. 4

	LENGTH	WIDTH	RATIO
	2.635 cm.	1.127 cm.	
	2.631 cm.	1.123 cm.	
Average	2.633 cm.	1.125 cm.	2.34

EXERCISE II. THE MICROMETER CALIPER

Problem. — *Measure the diameter of a pin and also measure the thickness of a piece of sheet metal.*

Apparatus. — The **micrometer caliper** (Fig. 7); a small **magnifier.**

Directions. — To use the instrument, turn the screw by grasping the milled head, *H*, between the thumb and finger of the right hand and turning to the right until the clicking of the ratchet dog is heard, showing that contact is made. In some forms of the caliper the head slips around when contact is made. The face, *B*, should now touch *C*, the zero line of the graduated edge of the sleeve, *E*, should register with the line that runs lengthwise of *A*, and the edge of the sleeve should coincide exactly with the zero line of the scale. If not, the caliper is out of adjustment, and should be put in adjustment by turning the screw, *K*.

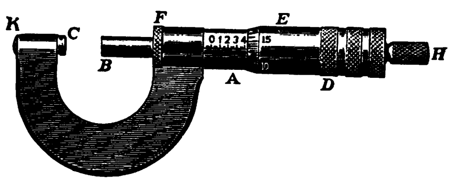


Fig. 7

Now turn the milled head, *H*, to the left until there is a small

space between C and B. The value of this space is found by noting the number of whole millimeter spaces exposed on A, as 4 in the illustration. To this add the value of the partial space next to the edge of the sleeve, E. The edge of the sleeve in the caliper illustration is divided into fifty parts, two revolutions of H being necessary to advance B one millimeter.* If this fractional space is less than half of a millimeter, a fact easily determined by the eye, then its value is the number of the divisions on the head that coincides with the index line on A. In the illustration the reading on the sleeve is 13.5, and the whole space between B and C is 4.135 mm. If this space is greater than half of a millimeter, 50 must be added to the circular head reading.

Hence, to measure the thickness of any small object, as the pin, or the sheet of metal, place it between B and C, turn H until contact is announced by the clicking of the ratchet or the slipping of the head, and read the scale as already explained.

The use of a small magnifier is indispensable in making the readings. It is a common occurrence to find the scale division not exactly coinciding with the index line. In that case an estimate is made of the third figure of the decimal part. The instrument operates with great precision, the errors being those made in reading the scale.

Form of Tabulation. — Record the measurements as in the following example : —

	Pin	Sheet Metal
	0.46 mm. 0.47 mm.	0.213 mm. 0.212 mm.
Average	0.46 mm.	0.212 mm.

* In some instruments the circular head is divided into 100 parts and only one revolution of H is necessary to advance B one millimeter.

EXERCISE III. THE VERNIER CALIPER

Problem. — *Measure the length and the diameter of a brass cylinder. Calculate its volume. Check the result by displacement in water.*

Apparatus. — The **vernier caliper** (Fig. 8); a cylindrical **glass graduate** (Fig. 9); an **Erdmann's float** (Fig. 10).

Directions. — By pressing the thumb against the knob, *C*, of the caliper, it frees the jaw, *B*, and permits it to slide freely

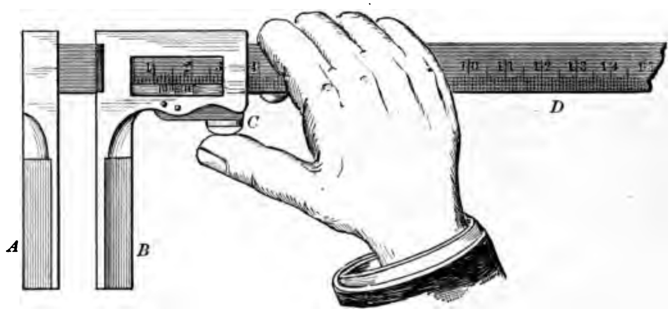


Fig. 8

on the limb, *D*. Now place the cylinder between the jaws, with its axis parallel to the limb, and push *B* firmly against its end.

To read the length, note the number of centimeters and whole millimeters shown on the limb to the left of the zero or index line on the vernier scale, the scale on the sliding jaw. Usually the index line, or zero line on the vernier scale, does not coincide with a division line on the limb; a part of a millimeter intervenes. To get the value of this piece, run the eye along the vernier scale until a division line is found which does register with one on the limb; the reading of this vernier line will be the number of tenths of a millimeter that this

space in question equals. In Fig. 8 the reading is 1.14 cm. A small magnifier must be used in making these readings.

Obtain the diameter in a similar manner.

The volume is calculated by the rule or formula $\pi R^2 H$, in which π is 3.1416, R is the radius of the cylinder, and H is the length.

To check this volume, ascertain the amount of water that the cylinder will displace (§ 6).* To do this, fill a glass cylinder graduated to read in cm.^{3}, part full of water. Since the water climbs up a short distance on the side of the graduate, it is difficult to determine exactly the surface reading. Hence, use an *Erdmann's float*, placing it in the graduate by means of a wire hook. Around the middle of the float there is a line serving as an index line. This line will be a little below the surface of the water. Drop the eye until the line of sight is in the plane of this circular line; it will then be normal to the scale on the graduate. The point where this line of sight cuts the scale gives the first reading to record. Now remove the float, placing it in a tumbler of water. Tip the graduate over a little and let the cylinder slide gently into the water. Reintroduce the float and take the second reading. The difference between the two readings will be the volume. Fractions of cm.^{3} must be estimated. The removal of the float from the graduate takes a little water with it by adhesion. Practically an equal amount will be returned when the float is replaced.

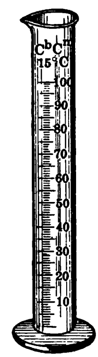


Fig. 9

What principle of physics is applied in this method? Why is it necessary to have the line of sight normal to the scale in making a reading?

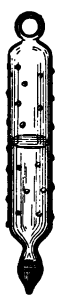


Fig. 10

* **References distinguished with a section mark are to Carhart and Chute's *First Principles of Physics*.**

Form of Tabulation. — Record the observations as follows: —

	Length cm.	Diameter cm.	Computed Volume $cm.^3$	First Float Reading $cm.^3$	Second Float Reading $cm.^3$	Volume $cm.^3$	Difference
	2.22	1.28		54.9	57.8	2.9	
	2.23	1.29		81.4	84.1	2.7	
Average	2.22	1.28	2.86			2.8	0.06

EXERCISE IV. THE CIRCULAR PROTRACTOR

Problem. — *Measure the angles of a triangle, find their sum, and calculate the per cent of error.*

Apparatus. — A **protractor** (celluloid), graduated to degrees or half degrees (Fig. 11).

Directions. — The triangle whose angles are to be measured is drawn with a sharp pencil by the instructor on a page of the notebook. To measure one of the angles, place the center of the graduated arc of the protractor exactly on the vertex of the angle, the diameter exactly on one side of the angle with the graduated arc extending over the angle. The line of sight must be normal to the surface. Why? The protractor being nearly transparent, the sides of the angle can be clearly seen through it, and their intersections with the graduated arc easily read. Each of the angles of the triangle is to be meas-

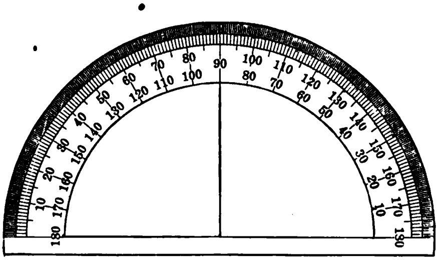


Fig. 11

ured in this way. If the sides of the triangle are too short to reach out to the graduated arc, prolong them until they do. The average of two measurements may be taken as the size of the angle. The sum should be 180°. Calculate the per cent of error. What are the chief sources of error ?

Form of Tabulation. — Record measurements as follows: —

	Angle *A*	Angle *B*	Angle *C*	Sum of Angles	Error	Per Cent of Error
	73°.0	64°.0	42°.0			
	72 .5	65 .5	42 .5			
Average .	72 .7	64 .7	42 .2	179°.6	0°.4	0.2

EXERCISE V. THE BEAM BALANCE

Problem. — *Find how many 10-cent pieces can be made out of a silver dollar.*

Apparatus. — A **beam balance** (Fig. 12); a **box of metric weights** (Fig. 13). The ivory scale, in front of which the balance pointer swings, is shown in Fig. 14. The box of weights is planned to provide a special place for each weight. It contains a pair of weight lifters for handling the flat weights.

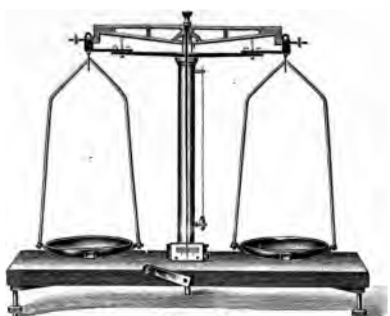


Fig. 12

Directions.—*Counterpoise Method.* — Adjust the balance by means of the leveling screws so that when in action the middle point of the ivory scale bisects the arc through which the pointer swings. Now place the article to be

weighed on the left-hand pan, and such a weight on the right-hand pan as, in your judgment, will about balance it. Turn the arresting button of the balance to throw it in action, and observe the movement of the pointer. If it goes sharply to the right, the weight chosen is too light; if to the left, it is too heavy. If too heavy, substitute the next lighter weight in the series; if now too light, add the next weight; if now too heavy, remove the last one added and replace it by the next lighter one. Proceed in this systematic way of adding and substituting until the pointer swings back and forth across the ivory scale through arcs which are bisected by the middle point of the scale.

To count correctly the weights on the pan, write down decimally in the notebook, in form for adding, the weights that are absent from the box; then remove the weights from the pan, one by one, putting them in their proper places in the box, checking each weight on the list just made. The sum of these weights will be the weight of the object.

Fig. 13

The record will consist of a list of the weights as described.

The Vibration Method. — Unless the balance has been very carefully adjusted the middle point of the ivory scale will not be the point at which the pointer stops when the balance, with its pans equally loaded, comes to rest. To find this resting point, set the unloaded balance in action and record the limit of the pointer's swing as observed on the ivory scale for three

successive passages across it, giving five successive readings of the turning points. Three of these will be on the side first read, and two will be on the other side. The first and the last reading will mark the farthest point from and the nearest point to the true resting point of the five points observed, and both of these are on the same side. To calculate the resting point, average separately the left-hand turning points and the right-hand turning points and find the mean of these averages. For example: let the scale be divided into 12 parts, and let the observed turning points be as follows:—

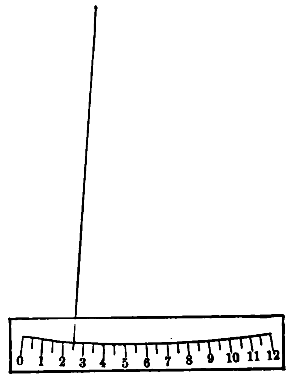


Fig. 14

	LEFT	RIGHT	RESTING POINT
	2.5 2.8 3.2	11.0 10.5	$\frac{2.8 + 10.7}{2} = 6.7$
Average . .	2.8	10.7	

The indicated resting point is 6.7. If the unloaded balance is set in action and is left undisturbed, it will come to rest with its pointer on 6.7. This is called the *resting point of the unloaded balance,* and it will be the point at which the loaded balance will come to rest if the pans are equally loaded. In calculating resting points one place of decimals is sufficient, since the first decimal figure in the observed turning points is a doubtful quantity.

Having found the resting point of the unloaded balance, place the article to be weighed on the left-hand pan and

counterpoise it as directed in the first method. This is not done to the same degree of precision as in the first method; all that is necessary is to add weights sufficient to cause the pointer to swing by the middle division of the scale. When this condition is secured, determine the resting point by observing five consecutive turning points, as already explained. If this resting point is larger than that for the unloaded balance, it indicates that there are not enough weights on the pan for a true balance; if smaller, then there are too many. Instead of laboriously changing the weights to secure a balance, determine by calculation what correction to make.

This is done as follows: Add a 2-mgm. weight to the right-hand pan and redetermine the resting point. This will be less than that last determined. To illustrate: let the resting point for the unloaded balance be 6.7, that for the loaded balance 7.4, and after the 2-mgm. weight is added, 6.9. It appears that the 2-mgm. weight has moved the pointer from 7.4 to 6.9, or 0.5 division. For true balance the pointer must be moved from 7.4 to 6.7 division. Therefore, the weight necessary to move the pointer this distance is given by the following proportion: $\frac{0.5}{0.7} = \frac{0.002}{x}$, from which $x = 0.0028$ gm. This *added* to the weights on the pan before the 2-mgm. weight was added gives the weight of the object. If the second resting point is *less* than the first, the calculated correction must be *subtracted.* The weights on the pan are to be counted and recorded as directed in the first method.

To work successfully with a balance, the following points should be observed: —

1. *The dust on the scale pans must be removed with a soft brush.*

2. *The observer must place himself squarely in front of the balance, with his notebook on the table between himself and the balance, and with the box of weights on the right-hand side.*

3. *The observer should manipulate the arresting button with his left hand and lift the weights with his right hand.*

4. *The balance must be at arrest when adding or removing weights.*

5. *The balance should be arrested just as the pointer is passing the middle point of the scale. This will prevent jar and displacement of the beam on its bearings.*

Form of Tabulation. — Record the observations as follows: —

WEIGHT OF 10-CENT PIECE

Unloaded Balance		Loaded Balance		0.002 Gm. Added		Weights on Pan
2.5	9.8	3.1	10.3	2.8	9.8	2.0 gm.
2.8	9.5	3.4	10.0	3.2	9.7	0.2
3.2		3.8				0.1
				3.7		0.05
R.P. = 6.2		R.P. = 6.8		R.P. = 6.4		2.35

Correction to be added: $\frac{0.4}{0.6} = \frac{0.002}{x}$, $x = 0.0030$ gm.

True weight: $2.35 + 0.0030 = 2.3530$ gm.

A similar tabulation will be necessary for the silver dollar.

CHAPTER II

MOLECULAR PHYSICS

EXERCISE VI. SURFACE TENSION

Problem. — *Observe and describe some of the phenomena of surface tension.*

Apparatus. — A **tumbler of water**; two **sewing needles**; a **glass tube** of small bore; **alcohol**; a small **rectangular frame** of wire; a **soap solution**; etc.

Directions. — Place a sewing needle carefully on the surface of a tumbler of water. This is easily done by bending up the ends of a brass hairpin, so that the needle will lie across the prongs without rolling off, and then lower it to the water, keeping the needle horizontal. Why does the needle float? Would a nail float? Why? Examine the surface of the water near the needle. Make a sectional drawing, cutting the needle at right angles. Write a description of the appearance of the surface.

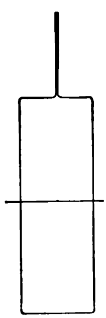


Fig. 15

Place a second sewing needle on the water parallel to the first and about 3 cm. distant. Dip the glass tube into alcohol and let a drop fall on the surface of the water between the needles. Describe the behavior of the needles. Let a drop of the soap solution fall between the needles and note the effect.

Dip the rectangular wire frame (Fig. 15) into the soap solution and get a film across it. Lay a small wire across the middle of the frame. Dip the glass tube in alcohol and break with it the film on one side of the small wire. Account for the behavior of the wire.

Cut out of wood a figure of the form shown in Fig. 16. Place a piece of camphor gum, the size of a grain of wheat, in the notch and float the whole on clean water. Account for its behavior. Touch the water with an oily finger and note the effect. Explain.

Fig. 16

Fill a clean glass tumbler with tap water. Scatter lycopodium powder evenly over the surface. Touch the surface of the water with the finger slightly oiled by contact with the hair. Note the effect and explain.

Scatter lycopodium powder evenly over the surface of clean water in a tumbler. Then touch the surface with (1) a crystal of sodium carbonate, (2) a crystal of sodium chloride, (3) a crystal of sodium hypochlorite, (4) a stick of caustic soda, (5) a crystal of sodium sulphate. The surface of each crystal should be scraped to remove any grease that may be there from handling. Describe the effect in each case.

Fill a tumbler with clean water. Scatter lycopodium powder evenly over the surface. Hold a red hot metal ball near the surface and describe the effect.

In discussing the observations, point out what they indicate to be the nature of the surface of the water. Give an explanation of this surface condition.

Form of Tabulation. — Record the work in two columns, *Conditions* and *Observations*. The first column will describe briefly what was done. Opposite each, under *Observations*, record what took place.

EXERCISE VII. THE FORMATION OF DROPS

Problem. — *Observe the forming of drops, and determine some of the conditions that govern their size.*

Apparatus. — Two **air thermometer bulbs** of different diameters; a **funnel** with a short piece of glass tubing attached to

its stem with a short piece of rubber tubing; a **pinchcock**; a **wooden support**; a **balance**; a glass **beaker** of 50 $cm.^3$ capacity; a **solution of soap.**

Directions. — Set up the apparatus as shown in Fig. 17, using the smaller bulb. The glass bulb must be thoroughly cleansed by dipping it in a hot mixture of chromic acid and sulphuric acid and rinsing in clean water. Adjust the pinchcock beneath the funnel until the water flows evenly over the bulb and drops from the under side. If the water flows in streaks down the surface of the bulb, the bulb is not clean and must be treated again. As the drops form, grow, and fall from the under side of the bulb, picture in a series of drawings the successive appearances of a drop from its first appearance to its completion.

Fig. 17

The water in the funnel must be kept at a constant level. Why? Adjust the pinchcock until the drops fall at the rate of one per second. Then collect 50 drops in the beaker whose weight has been found, and find the combined weight. Deduct the weight of the beaker, and divide the remainder by 50, to get the mass of a single drop. This mass in grams will be the volume in $cm.^3$ Why? Repeat the work and average the results.

In like manner determine the drop size for a rate of two drops per second.

Substitute the large bulb for the small one, and find the volume of a drop when the rate is one per two seconds.

Add soap solution to the water and repeat the work.

In the discussion compare the results with a view of ascertaining what laws are shown to govern the drop size. Also point out how a drop grows and why its size is affected by the conditions tested.

Form of Tabulation. — Record the observations as follows: —

Liquid Used	Size of Bulb	Drop Rate	Weight of Beaker	Weight of Beaker and 50 Drops	Weight of 50 Drops	Volume of One Drop
Water	Small	1 per sec.	. . . . .	. . . . .		
			Average	. . . . . /	. . . . .	. . . . .
Water	Small	2 per sec.	. . . . .	. . . . .		
			Average	. . . . . /	. . . . .	. . . . .
etc.	etc.	etc.		etc.	etc.	etc.

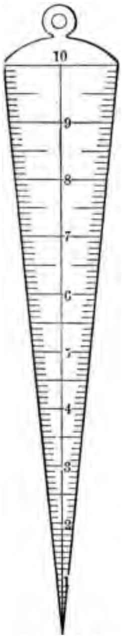
EXERCISE VIII. CAPILLARY ACTION

Problem. — *Determine the laws of capillary action.*

Apparatus. — Five **capillary tubes** of different diameters; a **tube gauge** (Fig. 18); a glass **beaker**; a **steel scale** (Fig. 19); a **wooden support**; a **dropper** (Fig. 20).

Directions. — Clean each of the tubes by connecting them one at a time to the dropper by a short piece of small rubber tubing. Dip the end of the glass tube in an ounce bottle half full of the cleaning liquid used in Exercise VII. Then by alternately compressing and relaxing the bulb, the liquid is churned up and

down in *the tube.* Thoroughly rinse the tube by using water in the same manner.



·Fig. 18

Now attach the tube to the V-scale by means of two elastic bands. The tube should project a centimeter beyond the point of the scale. Support the tube vertically by means of a clamp support, with the point of the V-scale just touching the surface of the water in a beaker (Fig. 21). Lift up the beaker so that the water may wet the tube for several centimeters, then lower and read the height of the water in the tube, reading on the scale at the bottom of the concave surface. Repeat the work three or four times, always wetting the tube before taking the reading. Record these readings in millimeters and find their mean. Proceed in this manner with each tube.

If the diameter of the tube is not known, it is found by inserting the tube gauge in the end of the tube and by the aid of a magnifier reading on the scale where the plane of the end of the tube cuts the scale. The result will be in millimeters.

In reading the height to the bottom of the meniscus, the small amount of water above this forming the curve was not considered. To correct approximately for this, increase the height by one sixth of the diameter. Multiply this corrected height by the corresponding diameter; the products will be nearly the same for all the tubes, showing that the height to which the water rises varies inversely as the diameter of the tube.

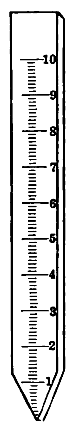


Fig. 19

Fig. 20

Select any one of the tubes and find in succession the height

to which hot water, alcohol, and water to which a little soap has been added rises.

In discussing the results, compare them with those of Exercise VII, and ascertain if there is any resemblance. Point out what laws are suggested by the data, and wherein lies the suggestion.

Fig. 21

Using the diameter and corrected height for cold water as coördinates, plot a curve (5).

Form of Tabulation. — Record the results as follows: —

DIAMETER OF TUBE D	HEIGHT FOR COLD WATER	HEIGHT CORRECTED FOR DIAMETER H	$H \times D$	HEIGHT FOR HOT WATER	HEIGHT FOR ALCOHOL	HEIGHT FOR SOAPY WATER
. . . mm.	. . . . mm.			. . . . mm.	. . . . mm.	. . . . mm.
	. . . . mm.			. . . . mm.	. . . . mm.	. . . . mm.
	. . . . mm.			. . . . mm.	. . . . mm.	. . . . mm.
Mean	. . . . mm.	. . . . mm.	. . . . .	. . . . mm.	. . . . mm.	. . . . mm.
. . . mm.	. . . . mm.					
	. . . . mm.					
	. . . . mm.					
Mean	. . . . mm.	. . . . mm.	. . . . .			

EXERCISE IX. CRYSTALLIZATION

Problem. — *Study the growth of crystals, some of their forms and modes of grouping.*

Apparatus. — A **saucer**; a **beaker**; a **test tube** on foot (Fig. 22); **ammonium chloride, common alum, sodium sulphate, common salt, sodium hyposulphite, zinc chloride,** etc.

Directions. — Prepare with hot water a saturated solution of the chemical salt to be studied. *First.* Pour a teaspoonful of the solution in a saucer and set aside. In a few hours, the bottom of the saucer will be covered with regular forms or crystals. Study their shape under a small magnifier; note any plan that they may exhibit in their grouping. *Second.* Fill a test tube on foot with some of the solution. Suspend a string in the solution from a match resting on the top. In a few hours, crystals in numbers will cluster along the string. Study them as before. *Third.* Pick out a single crystal from those formed in the saucer, add to it a teaspoonful of the saturated solution and set away. After a time examine the crystal, note its size, and the manner in which it has grown. *Fourth.* Examine a group of crystals on the string of the second case and note how they separate from one another.

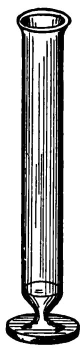


Fig. 22

The record should be a plain, carefully worded account of what is seen in each case, making drawings, if possible, showing form of crystals.

EXERCISE X. ELASTICITY

Problem. — *Ascertain the relation that the distortion of an elastic body sustains to the distorting force.*

Apparatus. — A **spiral spring,** made by winding spring brass wire, No. 24, on an iron rod of about 1 cm. diameter; a small

scalepan of known weight; a **box of metric weights**; a **linear scale**. Figure 23 shows the complete apparatus, in which *A* is a board to be supported in some suitable manner, *S* is the spring to be tested, and *I* the index to mark the elongation.

Directions. — Record the reading of *I* on the scale with no weights in the pan. Place a 5-gm. weight in the pan and record the reading of the pointer. Increase the weights in the pan to 10 gm. and record as before. Proceed in this manner until the limit of the scale is reached or until the pointer does not return to the first reading when all the weights are removed from the scalepan.

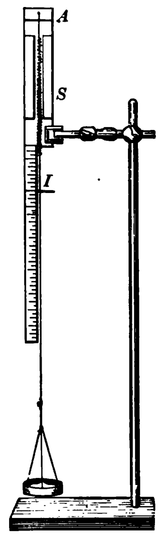


Fig. 23

Compute the stretching force in each case by adding the weight of the pan to the weights on the pan. Compute the elongation for each load; also the elongation per gram for each load. Are these equal? If so, what law expresses this fact? What application is made of this fact?

Plot the data on cross-section paper, using the elongations and the corresponding loads as coördinates (5). The graph will be practically a straight line, indicating that the relation between the strain (the distortion) and the stress (the distorting force) is one of the first degree; that is, strain varies as stress.

Form of Tabulation. — Provision for the following must be made in the tabular scheme: the *weight of the pan*, the *load* on the pan each time, the *stretching load*, the corresponding *index readings*, the *elongations*, the *elongations per gram*.

CHAPTER III

MECHANICS OF FLUIDS

EXERCISE XI. BUOYANCY

Problem. — *Ascertain the measure of the buoyant force on a solid submerged in water.*

Apparatus. — A **balance**; a **box of weights**; a **metal cylinder**; a **vernier caliper**; a small **bench** to place over one of the scalepans to support a beaker of water.

Directions. — *First.* Measure the length and the diameter of the cylinder with the vernier caliper, compute the volume, and record as directed in Exercise III. *Second.* Weigh the cylinder and record as directed in Exercise V. *Third.* Suspend the cylinder by a fine thread from the hook at the top of the bail of the left-hand scalepan, so that it is completely submerged in a beaker of water supported on the bench as shown in Fig. 24, and find its weight.

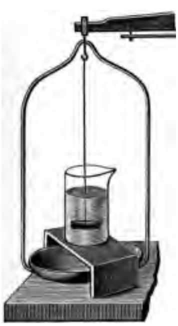


Fig. 24

The first weight exceeds the second, the difference being the buoyancy of the water on the cylinder. The volume of the cylinder gives the volume of the water displaced, from which the weight of the water displaced is known. Compare this with the buoyancy. What principle states the fact illustrated by the data obtained? Why is there a buoyant force in water and none in sand?

A little difficulty may be experienced in weighing the body when suspended in water. The surface tension of the water and its viscosity impede the free vibration of the balance.

In addition to the record already provided for, at the end collect into a table all the results, such as the *volume* of the cylinder, the *weight* of the cylinder in air, the *weight* in water, the *weight* of the water displaced, the *buoyancy*, the *difference*.

Form of Tabulation. — Record the results as directed.

EXERCISE XII. THE DENSITY OF A SOLID

Problem. — *Find the density of a heavy substance insoluble in water.*

Apparatus. — A **balance**; a **box of metric weights**; a **beaker**; a small **bench** as in Exercise XI.

Directions. — Weigh the solid in air and then weigh it suspended in water as in Exercise XI. The difference between these weights will be the weight of a volume of water equal to that of the body. Why? This divided by the density of water will give the volume of the body (§ 59). The weight of the body in air divided by the volume will be the density.

Air bubbles are liable to adhere to the body when submerged in water and increase the displacement. Remove them as far as possible with a wire. If the viscosity of the water prevents the vibration of the balance, then bring the pointer as near as possible to the true resting point by adjusting the weights on the pan.

The discussion should state the purpose of each step taken, especially that of weighing the solid submerged in water. Why is water used as the liquid? Could water be used for all solids? Explain.

Form of Tabulation. — Record each of the weighings as previously directed, and *collect the results* into a table at the end.

EXERCISE XIII. THE DENSITY OF A SOLID

Problem. — *Find the density of common cork, a solid that floats on water.*

Apparatus. — A **sinker of metal**; the **balance**, etc., of Exercise XII.

Directions. — *First.* Weigh the cork as directed in Exercise V. *Second.* Attach the metal sinker and weigh both submerged in water (Fig. 25). *Third.* Weigh the sinker submerged in water. The cork in air and the sinker in water together weigh more than both in water because of the upward pressure of the water on the cork when the latter is also submerged. This buoyancy, or the weight of a volume of water equal to that of the cork, equals the weight of the cork in air added to that of the sinker in water less the weight of both in water. This difference divided by the density of water is the volume of the cork. The density of the cork is the quotient of the weight of the cork in air by its volume. The same precautions must be taken in this problem as in Exercise XII, and the discussion will be similar in character.

Fig. 25

The Form of Tabulation. — Provide for three complete weighings, and *conclude with a summary* of the results.

EXERCISE XIV. THE DENSITY OF A LIQUID

Problem. — *Find the density of a solution of common salt.*

Apparatus. — A **balance**; a **box of metric weights**; a **density bottle** (Fig. 26); a **density bulb** (Fig. 27); a **hydrometer** (Fig. 28).

Directions. — *First Method.* — Clean the density bottle by rinsing it out with hydrochloric acid, then with distilled water,

and finally with ethyl alcohol. Dry the bottle by inserting a glass tube and drawing air through the bottle by suction.

Fig. 26

Weigh the bottle by the method of Exercise V. Fill it full of the liquid, insert the stopper carefully, dry the bottle with a cloth without touching it with the naked hand, and find its weight.

From the data calculate the weight of the liquid and divide it by the volume of the bottle, usually 25 cm.^{3} The quotient is the density.

In filling the bottle, the cork should be permitted to settle down of its own weight. The excess liquid will flow out through the capillary opening in the stopper. To force it in may burst the bottle (§ 45).

Check the work by filling a tall jar with the solution from which the sample used in the bottle was taken and floating the hydrometer in it. The density is read directly from the graduated scale on the stem (§ 61). Explain each step in the discussion of the problem.

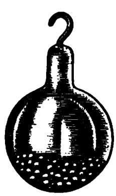


Fig. 27

Form of Tabulation. — Record each *weighing* as previously directed, each under its appropriate heading. *Collect results* at the end in a table.

Second Method. — Weigh the density bulb. Then weigh it suspended in water (Exercise XI). Finally weigh the bulb suspended in the liquid (solution of common salt). The difference between the first two weighings will give the weight of the water displaced by the bulb. Why? From this the volume of the bulb is found. How? The difference between the first and the last weighing will give


Fig. 28

the weight of a volume of the liquid equal to that of the bulb. Why? This weight divided by the volume of the bulb will be the density of the liquid. Why?

Check the work by the hydrometer (§ 61), as described under the first method.

Discuss this problem by explaining each step.

Form of Tabulation. — Follow the plan given for problems in weighing. Record each part under an appropriate heading. *Summarize the results at the end.*

EXERCISE XV. THE PRESSURE OF THE AIR

Problem. — *Measure the pressure of the air on a sheet of paper on the table.*

Apparatus. — An **aneroid barometer** (Fig. 29); a **linear scale** (Fig. 30).

Directions. — Measure the length and the breadth of the sheet of paper and calculate the area. Rest the barometer on the sheet of paper, face upward, tap the frame gently with the finger to assist the mechanism of the instrument in overcoming the friction of the bearings, and record the reading of the pointer. This will be the height of a column of mercury that will exert the same downward pressure as the atmosphere does at that place (§ 70).


Fig. 29

The product of the area of the paper in $cm.^2$ by the barometer reading in cm. will be the volume in $cm.^3$ of the quantity of

mercury whose weight is the pressure sought. Since 1 cm.^{3} of mercury weighs 13.6 gm., then 13.6 multiplied by the volume of the mercury will be the pressure in grams (§ 68).

If the barometer gives its readings in inches, either reduce the reading to centimeters, or make all the measurements and calculations in the English System. The area of the paper in square inches multiplied by the barometer reading in inches

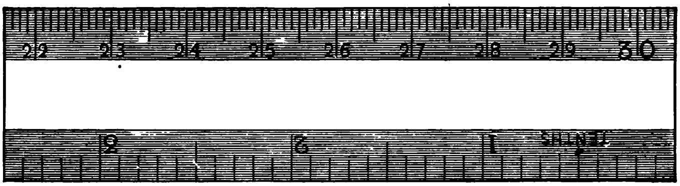


Fig. 30

will give the volume of the mercury in cubic inches, the weight of which is the atmospheric pressure. A cubic foot of water weighs 62.4 lb. A cubic inch of mercury weighs $\frac{62.4}{1728} \times 13.6 =$ 0.491 lb. Multiply 0.491 lb. by the volume of the mercury in cubic inches; the product will be the pressure in pounds.

Form of Tabulation. — Record the dimensions of the sheet of paper and the area calculated from the average of these measurements in parallel columns. To these add the barometer reading and the calculated pressure.

EXERCISE XVI. MEASUREMENT OF ALTITUDE

Problem. — *Measure the vertical distance from the floor of the basement of the school building to the highest accessible point of the building.*

Apparatus. — The **aneroid barometer** (Fig. 29).

Directions. — Place the aneroid barometer, face upward, on

the floor of the basement, tap the frame gently (Exercise XV), and note the reading. Then obtain the reading at the highest accessible point. The difference of these readings, expressed in millimeters, multiplied by 10.8 will be the vertical distance between these two points expressed in meters, since a difference in elevation of 10.8 m. produces a change of 1 mm. in barometric pressure.

If the aneroid is graduated in inches, then the difference of the two readings, expressed in hundredths of an inch, multiplied by 9 will be the distance in feet (§ 71).

A more accurate result is obtained by taking the temperature into account, but the rule is quite complex.

Form of Tabulation. — The student should prepare a suitable form of record.

EXERCISE XVII. COMPRESSIBILITY OF AIR

Problem. — *Test Boyle's law* (§ 74).

Apparatus. — A **barometer**; a **special device** shown in Fig. 31. This device consists of two glass tubes, connected by a heavy rubber tube, mounted to slide along a vertical support on which is a metric linear scale. One of these tubes is closed air-tight by a screw cap. Mercury is poured into the open tube in sufficient quantity to fill the glass tubes half full when supported side by side.

Directions. — Record the reading of the barometer in centimeters, and record any change that may take place during the progress of the experiment. Also record the reading on the vertical scale of the top of the capped tube and then screw on the cap. *It is important that this cap fit air-tight.* Now lower the open tube until the mercury comes nearly to its top. Record the position of the surface of the mercury in the closed tube and also in the open tube. Slide the open arm several centimeters up the scale and repeat the readings.

Continue in this way until the open tube reaches the top of the scale. If each reading of the surface of the mercury in the closed tube is subtracted from the reading at the top of that tube, the length of the inclosed air column in each case is obtained. As the tube is of uniform bore, this length may be considered as the volume of the air, since the volume will vary as the length. If the barometer reading is added to each reading of the surface in the open tube, and the corresponding mercury reading of the closed tube is subtracted from this sum, the difference will measure the pressure that the air in the closed arm is under.

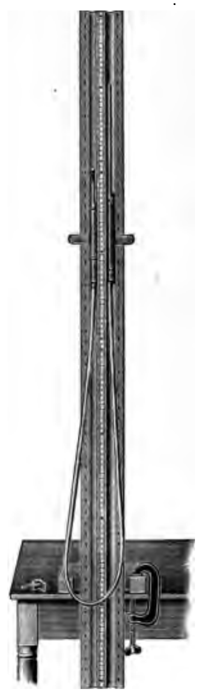


Fig. 31

To find out if any relation exists between the volume of the air, v, and the pressure, p, that it is under: multiply each v by the corresponding p. If these products are approximately equal, then the volume of the air varies inversely as the pressure. If the temperature of the room changes during the experiment, the product of v and p will vary. If the barometer reading changes during the experiment, the new value must be introduced into the calculations at the point observed. The rubber tube must hang freely and not rest on the floor or table, as any flattening of the tube will vary the reading because it changes its volume. If the air used is taken from the room, it will contain aqueous vapor and carbonic acid. Both of these impurities will tend to reduce the value of $v \times p$ as p increases.

Represent the data graphically, using the pressures as ordinates, and the volumes as abscissæ (5).

Form of Tabulation. — The following example shows the kind of results to be expected and the manner of recording them: —

Reading of Closed Tube		Reading of Open Tube	Reading of Barometer	Length of Air Col. v	Total Pressure p	$v \times p$
	cm.	cm.	cm.	cm.	cm.	
Top	119.4					
Bottom	90.3	67.4	73.8	29.1	50.9	1481
"	92.5	73.7		26.9	55.0	1479
"	96.2	86.6		23.2	64.2	1489
"	97.9	93.0		21.5	68.9	1481
"	99.3	99.5		20.1	74.0	1487
etc.		etc.		etc.	etc.	etc.

CHAPTER IV

MECHANICS OF SOLIDS

EXERCISE XVIII. COMPOSITION OF FORCES

Problem. — *Find the resultant of two parallel forces acting in the same direction, and its point of application.*

Apparatus. — Two 2000 gm. **drawscales**, smallest reading, 25 gm.; a **wooden bar**, 50 cm. × 1 cm. × 1 cm., graduated to millimeters; a **kilogram weight**.

Directions. — Set up the apparatus as shown in Fig. 32. Adjust the drawscales to parallelism by means of a plumb line.* Before attaching the kilogram weight, record the reading of each drawscale so that a correction may be made in the final readings for the weight of the bar. Now attach the weight, not at the middle, and again read each balance. Also record the position of each drawscale

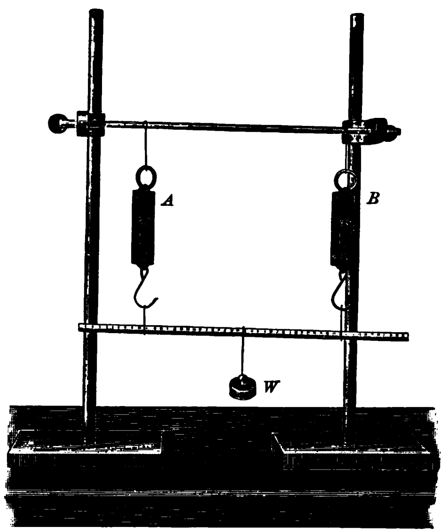


Fig. 32

* For a plumb line suspend a small lead ball by a thread.

hook, and of the kilogram weight on the bar. Correct each drawscale reading by the corresponding reading when the bar acts alone. Compare the sum of these corrected readings with the value of the attached weight. The difference, if any, will be the error. Calculate the per cent of error, the true resultant or weight being the base. Calculate the distance of each drawscale from the weight, the ratio of the left-hand drawscale to the right, using *corrected readings*, and the ratio of the distance of the weight from the right-hand drawscale to its distance from the left-hand one. If these ratios are equal, or nearly so, what law is sustained?

Give the weight a new position on the bar and repeat the work.

In discussing the work, explain one set of data throughout and point out the significance of the results.

Form of Tabulation. — The following record illustrates the method: —

	DRAWSCALE A	DRAWSCALE B	$A + B$	WEIGHT W	ERROR $W - (A + B)$	PER CENT OF ERROR
	gm.	gm.	gm.	gm.		
1st Reading	15	18				
2d "	475	559				
Cor'd "	460	541	1001	1000	1	0.01
etc.	etc.	etc.	etc.	etc.	etc.	etc.

POSITION OF A	POSITION OF B	POSITION OF W	DISTANCE W TO A	DISTANCE W TO B	RATIO OF A TO B	RATIO OF WA TO WB	DIFFERENCE
cm.	cm.	cm.	cm.	cm.			
15	35	25.8	10.8	9.2	0.85	0.85	0
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.

EXERCISE XIX. COMPOSITION OF FORCES

Problem. — *Find the resultant of two forces acting on a body at an angle.*

Apparatus. — Three **drawscales** with flat backs; stout **cord**; a **board** 80 cm. square, provided with a series of holes near its edges; three **iron pins** that fit the holes in the board; **a circular paper protractor** graduated in degrees from 0° to 360°.

Directions. — Lay each drawscale on the table, face up, and determine the reading of the pointer, when only sufficient tension is applied to take up the play in the parts. This may be a negative quantity, unless the instrument has seen hard usage, since a drawscale is graduated hanging vertically, with the weight of the hook stretching the spring. Record these readings as zero readings. Now set up the apparatus as shown in Fig. 33. Carefully adjust each drawscale so that the hookbar does not bear against the frame, the line of the string being straight with the slot in the face of the drawscale. The lengths of the cords should be such that each drawscale registers at least halfway down the scale. Now read each scale, place the protractor under the cords with the point of juncture of the cords exactly over its center, and with the cord of scale A passing through the zero of the circular scale, and record the reading of each cord on that scale. It is preferable, for ease in plotting the data, to have the drawscales marked, A, B, and C, and so placed that the order of reading is the same as that of the protractor.

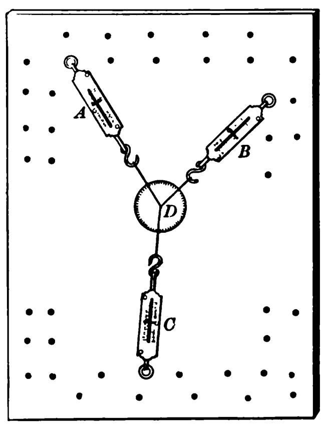


Fig. 33

To plot the data, draw on the page of the notebook, by means of a protractor, three lines making with each other the same angles as the cords. Lay off on these lines distances proportional to the corrected readings of the drawscales. Use some suitable scale for this, in which a centimeter represents a certain number of grams (§ 107). Complete the parallelogram on *A* and *B*, draw the diagonal through the point common to *A* and *B*, measure it in terms of the scale adopted for the drawing. The error will be the difference between this value and the reading of *C*.

Move the pins to new positions, thereby changing the angles and the drawscale readings for a second trial.

In discussing the work describe the process of finding the resultant.

Form of Tabulation. — Preface the record with a lettered diagram showing the order of the scales as used.

	Drawscale *A*		Drawscale *B*		Drawscale *C*	
Zero Reading . . .	– 10 gm.		– 15 gm.		0	
	Uncor'td	Cor'td	Uncor'td	Cor'td	Uncor'td	Cor'td
First trial	gm. 105 etc.	gm. 115 etc.	gm. 125 etc.	gm. 140 etc.	gm. 215 etc.	gm. 215 etc.

	Angle Read'g *A*	Angle Read'g *B*	Angle Read'g *C*	Resultant of *A* and *B*	Error
First trial	0° etc.	75° etc.	220° etc.	gm 204 etc.	gm. + 11 etc.

EXERCISE XX. CENTRIFUGAL FORCE

Problem. — *Test the law that centrifugal force is equal to* $\frac{mv^2}{gr}$.

Apparatus. — An **iron ball** of about 2 kgm. mass; a **drawscale**; a **meter stick**; a **try-square**; **brass wire** No. 20.

Directions. — Weigh the ball and then suspend it by a wire from a hook in the ceiling so that it swings to and fro across the table as a pendulum (Fig. 34). Place the meter stick on the table with the 50-mark exactly beneath the center of the ball when it is at rest. Pull the ball to one side, bringing its center exactly over some predetermined mark on the meter stick, as 30; that is, its center is 20 cm. from the middle point of its swing. To do this, rest the try-square on the table with the blade vertical and its edge marking division 30 on the meter stick, and then bring the center of the ball opposite this edge. Let the pendulum swing to and fro, counting the number of vibrations in a minute.

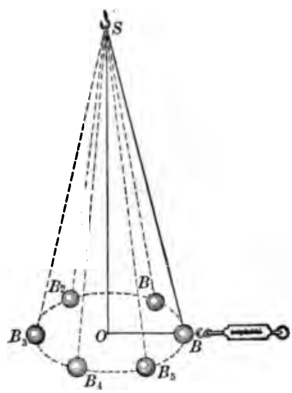


Fig. 34

In counting the vibrations, the student should face the plane of the pendulum arc and count the passages of the ball through the lowest point of its swing. From the data calculate the time of a complete vibration. This time may be considered the same as that required by the ball to make a complete revolution in a circle, swinging as a conical pendulum, the radius of the circle described being 20 cm. The ball as it swings in this circle is maintained in its orbit by centrifugal force. This force is equal to the pull necessary to hold the ball out from its lowest point *O*, to the position, *B*, 20 cm. from *O*.

To measure this force, attach a drawscale to a screw eye in the ball opposite its center, keep it parallel to the table, and pull the ball to the position, *B*. Knowing the radius of the circular orbit, the circumference is found by the relation, $2\pi R$. If this circumference is divided by the time of a complete vibration, the quotient will be the velocity per second. Express the *mass* of the ball in *grams*, the *velocity* in *cm.* per sec., the *radius* in *cm.*, and consider g as 980 cm. per sec. per sec. Substitute these values in the relation $\text{C. F.} = \frac{mv^2}{gr}$ (§ 128). The resulting force will be in grams, and the nearness of its agreement with that given by the drawscale measures the success of the work.

Make *three counts* in determining the time, using the *mean value* in the calculation. Explain each step in the discussion.

Form of Tabulation. — Record the results as follows: —

m	r	No. of Vibrations	No. of Seconds	t	v	Observed C. F.	Computed C. F.	Dif.
kgm.	cm.			sec.	cm. per sec.	gm.	gm.	gm.
1.9	25	34	55	1.618	48.60	185	183	3
		49	79	1.612		180		
		63	102	1.619		175		
			Mean	1.616		180		

EXERCISE XXI. THE PENDULUM

Problem. — *Verify the pendulum law, that the period of vibration varies as the square root of its length.*

Apparatus. — Figure 35 shows a simple and effective device for this problem.* The pendulum bob is an iron ball about

* One of the greatest difficulties in timing a pendulum is to start and stop the count on an exact coincidence of the experimental pendulum with the clock

2.5 cm. in diameter, suspended by a brass wire, No. 28, in front of a scale, 2 m. long. A steel needle projects through the ball and makes electrical connection with the mercury contact on a shelf at the bottom of the support. The pendulum is connected through a telegraph sounder with the laboratory clock in the manner shown in Fig. 36. The length of the pendulum is regulated by a sliding clamp on the standard. Counting time can always start and stop on a coincidence of the experimental pendulum with the laboratory clock, because every coincidence is announced by the clicking of the sounder beside the experimental pendulum.

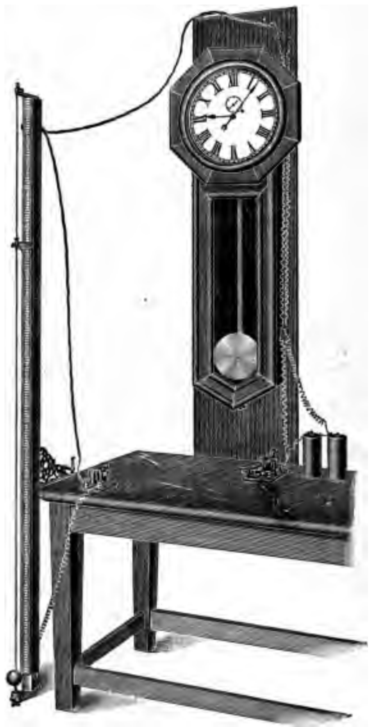


Fig. 35

Directions. — To obtain the length of the pendulum proceed as follows: Place a try-square against the support, with the blade reaching out to the pendulum and its upper edge in contact with the face of the clamp marking the center of suspension, and record the reading on the linear scale. In

pendulum. The electrical method of accomplishing this is one of the best. It gives only approximate results on account of the width of the mercury in the mercury contact. If one does not care for great accuracy, the coincidences may be judged by the eye, and a watch used in marking the time. Simpler methods of supporting the pendulum are shown in Figs. 37 and 38.

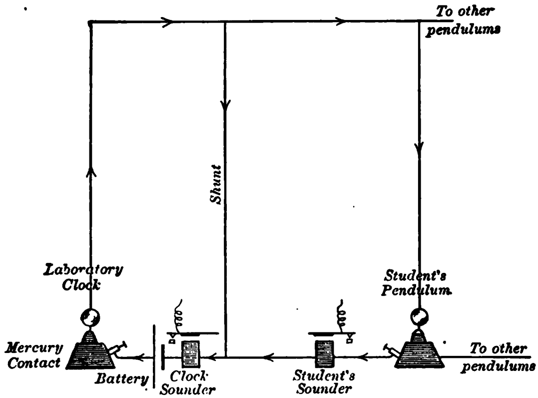


Fig. 36

like manner, find the reading on the scale for the top of the ball. Find with calipers the diameter of the ball. To the difference between the two scale readings add half the diameter of the ball. The sum will be the length of the pendulum.


Fig. 37

To find the time of a single vibration, set the pendulum oscillating through an arc not more than 10 cm. across. When the sounder clicks, one student seated directly in front of the pendulum counts every time it passes its lowest point, and a second student counts the vibrations of the laboratory clock as announced by the clock sounder. When the number of vibrations of the experimental pendulum approaches fifty, listen for the click of the sounder connected to the experimental pendulum; when heard, *give that count aloud* as a signal for the counting to stop. The number of clock vibrations divided by that of the experimental pendulum will be the time, or t. Express this to *four decimal places.*

In counting time, the first click, giving the signal

to begin, *should be called zero and not one.* There is great danger of *losing your count*, especially when the numbers are large. It is best to count by tens, keeping tally of the tens on paper. The larger the number of counts, the more accurate the time will be. If the mercury globule in the contact had no sensible diameter, it would be necessary to count only from one coincidence to the next one.

In beginning the work, put the slider at the top of the standard. Then for successive pendulums, shorten each time about 30 cm. Three pendulums will be sufficient.

Divide the time of the pendulum by the square root of its length, expressing the result to *four decimal places.* These quotients should be the same; that is, the two variables, t and $\sqrt{l}$, have a constant quotient, showing that the time of a pendulum varies as the square root of the length.

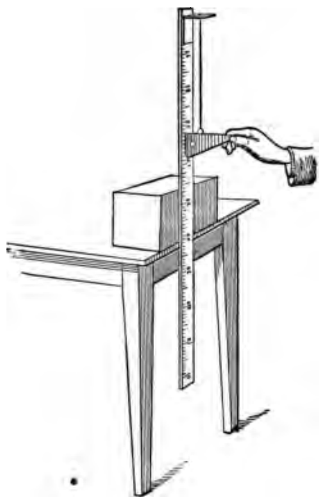


Fig. 38

In the discussion, point out the difficulties of the problem and give the *physical interpretation of the results.*

Form of Tabulation. — Record results as follows: —

Vibrations of Experimental Pendulum	Vibrations of Clock	Time t sec.	Data for l Top Reading cm.	Bottom Reading cm.	Diameter of Balance cm.	cm.	$t \div \sqrt{l}$
81	111	1.3704					
100	137	1.3700					
108	148	1.3704					
	Mean	1.3703	13.2	198.5	2.6	186.6	0.1003
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.

EXERCISE XXII. ACCELERATION OF GRAVITY

Problem. — *Measure the acceleration of gravity, or g.*

Apparatus. — The same as in Exercise XXI.

Directions. — Use the data obtained for the longest pendulum in Exercise XXI, and substitute the values of l and t in the relation $g = \frac{\pi^2 l}{t^2}$. Use the true value for g as a base, and calculate the per cent of error.

An inspection of the above relation shows that any error in measuring the length of the pendulum will be multiplied by the square of the ratio of π to t.

EXERCISE XXIII. PRINCIPLE OF MOMENTS

Problem. — *Find the relation between the moments of two forces acting on a body free to rotate when the body is in equilibrium.*

Apparatus. — A **meter stick** balanced on a support, as shown in Fig. 39; a **box of metric weights.**

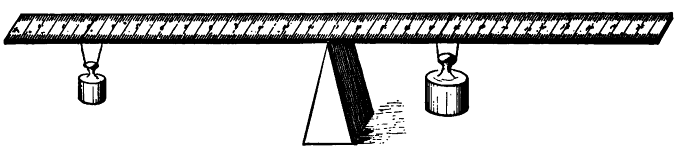


Fig. 39

Directions. — Balance the meter stick on the support. Suspend two weights by looped threads, 100 gm. and 200 gm., and by trial find positions for them on the balanced meter stick such that the balance is not disturbed. Record the distance of each weight from the supporting edge, and compute the moment of each force (§ 156). What effect does the 100-gm. weight tend to produce? The 200-gm weight? Try other

weights and compute the moments. What inference can be drawn from the results?

Form of Tabulation. — Use some such form as the following: —

Left-hand Weight	Right-hand Weight	Distance of L.H. from Pivot	Distance of R.H. from Pivot	Moment of L.H. Weight	Moment of R.H. Weight
gm.	gm.	cm.	cm.		
. . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
. . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
. . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .

EXERCISE XXIV. THE INCLINED PLANE

Problem. — *Test the principle of work (§ 150) in the case of the inclined plane and calculate the efficiency of the device used.*

Apparatus. — The **device** shown in Fig. 40, in which W is an accurately turned iron cylinder of 1 kgm. mass; a **box of weights**; a **strip of plate glass** to cover the plane.

Directions. — Find the weight of the scalepan and of the cylinder. Place weights in S sufficient to cause W to move steadily up the plane. Then remove enough weights from S to permit W to move down the plane at about the same rate as previously it moved up. Make several trials, recording the weights in the pan when W moves up and also the weights when W moves down. Find the mean of all of these results and increase this by the weight of the pan. This result will be the force required to move W up the plane if there were no friction, since the force that moved W up the plane was $F+f$, f being a quantity due to friction, and the force when W moved down was $F-f$.

Now measure the length and the height of the plane. The

table or board supporting the plane must be *leveled* at the *beginning* of the experiment. This is done with a spirit level.

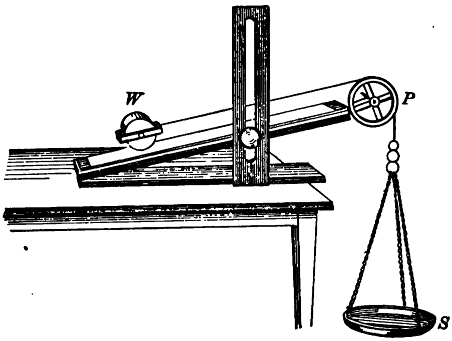


Fig. 40

The force applied, F, multiplied by the length of the plane, l, gives the work done by that force. The weight of W multiplied by the height of the plane, h, gives the work done in moving W against gravity to the top of the plane (§ 139). The difference of these two products is the error.

To calculate the efficiency of the device, multiply the average of the forces required to move W up the plane by the length of the plane. This will be the total work done on the machine. For the useful work, multiply the weight of W by the height of the plane. The quotient of the latter by the former will be the efficiency (§ 153).

Form of Tabulation. — Record the results as follows: —

Length l	Height h	Load w	Weight of Pan	Weight in Pan Going Up	Weight in Pan Going Down	F	$F \times l$	$W \times h$	Difference	Efficiency E
cm.	cm.	gm.	gm.	gm.	gm.	gm.	gm.-cm.	gm.-cm.	gm.-cm.	
. . .	. . .	. .	. .	. . .	. . .	. .	. . . .	. . . .	. . . .	. .
. . .	. . .	. .	. .	. . .	. . .	. .	. . . .	. . . .	. . . .	. .
. . .	. . .	. .	. .	. . .	. . .	. .	. . . .	. . . .	. . . .	. .

CHAPTER V

SOUND

EXERCISE XXV. RESONANCE

Problem. — *Find the length of the air column that reënforces a sound.*

Apparatus. — A **metal** or **glass tube**, about 2.5 cm. in diameter and 50 cm. long, supported in a clamp and having its lower end dipping in a jar of water (Fig. 41); a **thermometer**; two **tuning forks** of known pitch, as C 256, and G 384; a **meter stick**.

Directions. — Set the fork in vibration by striking a corner of a prong against a block of soft wood, and hold it over the open end of the tube. While the fork is in vibration, alternately raise and lower the tube in the water until a position is found at which the sound is loudest. Mark the position, and then try the effect of a position slightly below that, also one above it, returning for comparison to the position first marked until the best place is located. When found, measure the length of the air column. Suspend a thermometer (§ 301) within the tube for ten minutes and obtain the temperature of the air. Repeat the work several times and find the mean of the lengths. Now calculate the velocity of sound by the relation $v = 332.4 + 0.6t$, in which t is the temperature of the air on

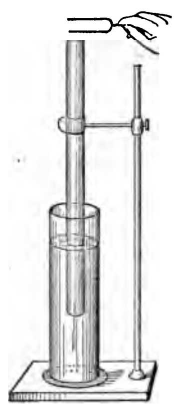


Fig. 41

the Centigrade scale (§ 304). Divide this velocity by the vibration rate of the fork; the quotient will be the wave length of the sound emitted by the fork (§ 197). Make similar tests with the other fork. Find in each case the ratio of the length of the air column to the corresponding wave length.

In the discussion explain the principle of resonance showing how long the air column should be.

Form of Tabulation. — Record the results as follows: —

Vibration Number n	Length of Air Column	Temperature	Velocity of Sound	Wave Length l	Ratio of Air Column to Wave Length
	cm.		cm. per sec.	cm.	
. . . . .	. . . . . .	. . . .	. . . .	. . . .	. . . .
	. . . . . .				
	. . . . . .				
Mean	. . . . . .				

EXERCISE XXVI. VELOCITY OF SOUND

Problem. — *Find the velocity of sound in air.*

Apparatus. — A **tuning fork** of known rate; a **thermometer**; a **device** shown in Fig. 42. This device is a tin tube about 5 cm. in diameter and 1 m. long, closed at the bottom. It is connected at the bottom to a small glass tube in front of a meter stick to mark the water level, and also by a long rubber tube to a large bottle or funnel filled with water. Listening tubes may be attached at the top, to be used when several such devices are in use in the room at the same time.

Directions. — Fill the tube two thirds full of water. Suspend the thermometer in the tube for ten minutes to get the temperature of the air. One of the operators should hold the vibrating fork steadily over the top of the tube. As the fork

vibrates, the other operator varies the length of the air column by alternately raising and lowering the vessel of water. At the same time he listens to the sound as it increases and decreases in loudness, noting the position of the water level in the tube against the linear scale when the sound is loudest. Now lengthen the air column to about three times the first length and locate a second length that reënforces the sound. The difference between these two values is half a wave length for the fork used (§ 216). This, multiplied by two, will be the wave length, and that by the rate of the fork will be the velocity of sound per second. Check the work by calculating the velocity by the relation $v = 332.4 + 0.6\,t$, in which t is the temperature of the air in the tube.

In the discussion point out any defects in the method.

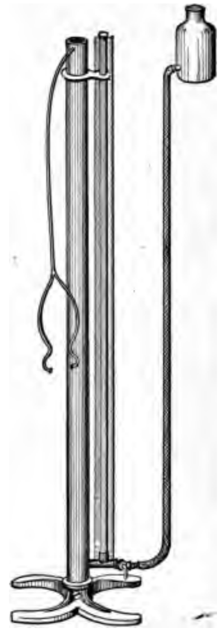


Fig. 42

Form of Tabulation. — Record the results as follows: —

Vibration Number n	First Air Column cm.	Second Air Column cm.	$\frac{1}{2}l$ cm.	Velocity by Resonance Method v in cm. per sec.	Temperature t	Velocity by Temperature Method v in cm. per sec.
320	26.5	79.6	53.2	340.5	20°.6	344.8
	26.3	79.2				
	26.0	79.4				
	26.2	79.5				
	26.4	79.6				
Mean	26.3	79.5				

EXERCISE XXVII. VELOCITY OF SOUND

Problem. — *Find the velocity of sound in a metal rod.*

Apparatus. — A special device known as **Kundt's apparatus** (Fig. 43).

Directions. — Clamp the metal rod exactly in the middle. The rubber membrane tied over the end of the glass tube should rest gently against the small cardboard disk that is cemented on the end of the metal rod. Very fine cork dust * is

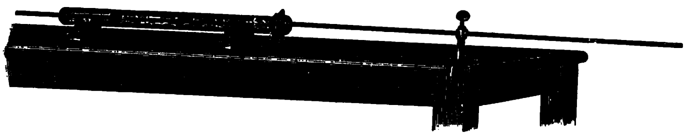


Fig. 43

scattered evenly throughout the tube. Stroke the free end of the metal rod either with a wet cloth or leather coated with powdered rosin. With a little practice the right pressure can be found at which the rod yields a clear sound of high pitch. The vibrations of the rod will be communicated to the air in the glass tube, and the cork dust will be violently agitated. Move the piston to and fro, until a position is found where the cork dust rises up in parallel plates each time that the rod is stroked, and falls back on itself in a series of ridges. These groups of ridges will be separated by heaps of undisturbed dust which will be evenly distributed within the tube from the piston to the membrane, dividing the space exactly into a number of equal parts.

Measure the distance from the inner face of the piston to the membrane. Count the number of segments into which the air

* Cork dust is prepared by filing a cork and sifting the product through a piece of wire cloth.

column is divided by the *undisturbed* dust piles. These dust piles mark the nodes, since the air column vibrates in segments (§§ 212, 219). The quotient of the length of the air column by the number of segments will be the length of one segment, s, or half a wave length, in air, of the tone emitted by the stroked rod. When a rod is clamped in the middle, it gives its fundamental when it vibrates with a node in the middle and an antinode at each end. Hence, the length of the rod, or l, is half a wave length for the same tone in the material of the rod. Then l divided by s will be the ratio of the velocity of sound through the rod to that through air. Find the velocity of sound in air by the relation $v = 332.4 + 0.6\,t$. This, multiplied by the ratio, $\frac{l}{s}$, will be the velocity of sound in the metal rod.

Repeat the work, giving the piston a different position, so that the number of segments will not be the same as before.

Form of Tabulation. — Record the measurements as follows: —

Length of Rod l	Length of Air Column a	Number of Segments	Length of Segments s	Temperature $t°$	Velocity of Sound in Air v per sec.	Velocity of Sound in Rod v per sec.
cm.	cm.		cm.		m.	m.
. . . . . .	. . . . .					
. . . . . .	. . . . .					
. . . . . .	. . . . .					
Mean . . .	. . . . .	. . . .	. . . . . .	. . . .	. . . . . .	. . . . . .

EXERCISE XXVIII. PITCH

Problem. — *Measure the frequency of a tuning fork.*

Apparatus. — A **tuning fork**; a **sonometer** (Fig. 44); a **wire micrometer** (Fig. 7).

Directions. — Tune a wire on the sonometer by varying the tension and by adjusting the position of the movable bridge under the wire until it emits a sound in unison with that yielded by the fork. Preferably, give the wire a fixed tension, as 8 kgm., and complete the tuning by moving the bridge. Approximate unison can be discovered by placing a rider * on the wire. If the rider jumps off when the stem of the vibrating fork touches the sounding board, the adjustment is close. In

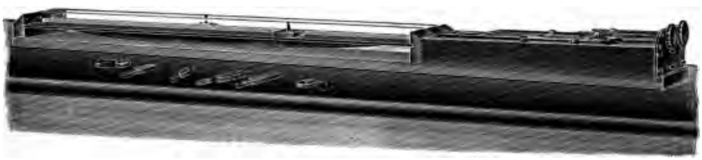


Fig. 44

perfect adjustment there will be no audible beats (§ 201); this can be determined by the ear.

Now measure with a meter stick (Ex. I) the length of the wire from the center of the top edge of the bridge to the center of the bridge at the end. Measure the diameter of the wire with the wire micrometer (Ex. II). Read the tension of the wire as shown by the drawscale. Repeat the work several times. Use the magnifier in reading the tension.

In the mathematical theory of vibrating strings it is shown that $n = \frac{1}{lD}\sqrt{\frac{T}{\pi d}}$, in which l is the length of the wire in centimeters, D the diameter in centimeters, T the tension in dynes (How are grams reduced to dynes ?), d the density of the steel wire, and π is 3.1416.

By substituting the mean values for these quantities in the above relation as they were determined by the experiment,

* A rider is made by folding into a Λ a piece of paper 1 mm. wide and 2 cm. long.

the frequency of the wire, and hence that of the fork, is found.

The weakness of this method is in the difficulty of tuning the wire to exact unison and in the additional fact that any error made in reading the tension is largely multiplied in reducing it to dynes.

Form of Tabulation.—Record the observations as follows:—

LENGTH OF WIRE l	DIAMETER OF WIRE D	TENSION T	DENSITY d	n
. . . . cm.	. . . . cm.	. . . kgm.	. . . .	. . . .
. . . . cm.	. . . . cm.	. . . kgm.		
Av. . . . . . cm.	. . . . cm.	. . . kgm.		

3

EXERCISE XXIX. VIBRATING STRINGS

Problem.—*Show the relation that the length, the mass, and the tension which a string is under sustain to its frequency.*

Apparatus.—Four **tuning forks** giving a major chord as C, E, G, and C'; a **sonometer**; a **wire micrometer.**

Directions.—*First.* Stretch a steel wire on the sonometer, giving it a tension of about 7 kgm. Shorten it by a movable bridge until it sounds in unison with the C-fork. Note carefully the length of the wire. Repeat and find the average. Now shorten the wire by moving the bridge until it sounds in unison with the E-fork and measure the length. In like manner find the length for the G-fork and the C'-fork. Multiply each length by the corresponding vibration ratio of the fork, as 4, 5, 6, 8. If these products are equal, or nearly so, it follows that the frequency varies inversely as the length. *Second.* Stretch two wires, one steel and the other brass, to equal tensions, the heavier having a movable bridge under it.

Find by trial a position for the movable bridge to put the wires in unison. Measure the length of these wires (Ex. I), and their diameters (Ex. II). Find the density of steel and of brass (App., Table I). Compute the mass of 1 cm. length of each wire (§ 59). Multiply each length by the square root of the mass per unit length. If these products are equal within reasonable limits of error, it follows that the frequency varies inversely as the square root of the mass per unit length. *Third.* Stretch two steel wires of the same diameter to different tensions, the wire of lowest tension having a movable bridge under it. Bring the wires to unison by moving the bridge. Measure the lengths and observe carefully the tensions. Divide each length by the square root of the corresponding tension. These quotients will be practically equal, showing that the frequency varies as the square root of the tension.

By using steel wires of different diameters and by proceeding as in the second case, it can be shown that the frequency varies inversely as the diameter of the wire. In like manner, by using a brass wire of the same diameter as the steel, it can be shown that the frequency varies inversely as the square root of the density. Both of these laws, however, are comprehended in the second law as stated. This is evident from the fact that the mass of a unit length varies as the square of the diameter when the density is constant, and varies as the density when the diameter is constant.

The chief difficulty in this problem is in securing accurate tuning. The rider will aid in securing approximate results. In measuring the tension, each must be corrected for the zero reading of the drawscale.

Form of Tabulation. — Record the results as shown on the next page: —

	Length of Wire C	Length of Wire E	Length of Wire G	Length of Wire C'
	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
Law I	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
Average	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
Frequency ratios	4	5	6	8
$n \times l$	. . . .	. . . .	. . . .	. . . .
	Diameter of Steel Wire	Diameter of Brass Wire	Length of Steel Wire	Length of Brass Wire
	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
Law II	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
Average	. . . . . cm.	. . . . . cm.	. . . . . cm.	. . . . . cm.
	Mass of Wire per Unit Length		$l + \sqrt{m}$	
	Steel	Brass	Steel	Brass
	. . . . . gm.	. . . . . gm.	. . . .	. . . .
	Tension of A kgm.	Tension of B kgm.	Length of A	Length of B
	Obs'd	Obs'd	. . . . . cm.	. . . . . cm.
Law III	Corr'n	Corr'n	. . . . . cm.	. . . . . cm.
	Corr'd	Corr'd	. . . . . cm.	. . . . . cm.
		Average	. . . . . cm.	. . . . . cm.
	$t \div \sqrt{l}$ for A . . . . . , for B			

EXERCISE XXX. OVERTONES

Problem. — *Determine what overtones characterize a vibrating wire.*

Apparatus. — A **sonometer** (Fig. 44).

Directions. — Stretch on the sonometer two steel wires of the same diameter and tune them to unison by adjusting the tension. Now pluck one of the wires near the end and listen to the tone for an instant. While the sound is still strong, touch the wire lightly at its middle point with the ball of the index finger. Compare the tone now emitted with that given by the other wire when shortened to one half by the movable bridge. What note is given by the half wire? What overtone is shown to be present in a wire when plucked near the end? Pluck the wire again near the end and notice whether you can detect this overtone in the complex sound emitted. Pluck the wire at its middle point and note the difference in the quality of the sound. Explain.

Pluck the wire and damp it at one third from the end. Compare the sound emitted with that given by the second wire shortened to one third. What is its pitch? Ascertain whether you can detect it in the complex sound emitted by the wire when plucked near the end. Pluck the wire one third from the end and compare. Explain.

Damp the wire one fourth from the end and test as before. Try one fifth.

What conclusions can be drawn regarding the mode of vibration of a wire? What overtones are present? Why is the quality of the tone affected by the place of plucking? Where should a wire be plucked to affect the quality of the sound the least?

Form of Tabulation. — Record the results in two columns, *Conditions* and *Observations.* State in the first column the tests made, and opposite each test the facts observed.

CHAPTER VI

LIGHT

EXERCISE XXXI. IMAGES BY SMALL APERTURES

Problem.—*Determine the nature of the images of objects that are formed by small apertures.*

Apparatus.—A **lamp**; a wooden **screen**, 30 cm. × 15 cm.; a **screen** with an **aperture** 5 cm. square; a **cylinder** of paper or sheet iron, 25 cm. high and 15 cm. diameter, with an aperture 2 mm. in diameter.

Directions.—Darken the room. Set up the apparatus as shown in Fig. 45. Cover the aperture in the apertured screen with a piece of opaque paper in which an aperture 2 mm. square is cut. Fasten a sheet of white paper on the other screen. Adjust the opaque cylinder, *L*, about the lamp until an inverted image of the lamp flame is seen on the apertured screen, *B*, and over the small aperture. A slight adjustment of the cylinder will bring one corner of the flame image over the aperture. The light from that point will pass through and strike screen *A* and form on it an image of the aperture in screen *B*. Trace the outline of this image on the screen with a pencil. Now move the cylinder so that light from a second point of the flame is tested.

The point tested is always the one marked by the part of the image that is over the aperture in screen *B*. Any point can be brought there by judiciously moving the cylinder, *L*. Take in succession points situated in the perimeter of the flame, and outline in each case the image on screen *A*. Trace a line through the centers of these images. Now remove the cylin-

der from the lamp and outline the image seen on screen *A*. These two tracings will either coincide or be nearly parallel, showing that the image of the lamp flame formed by the small aperture is a collection of images of the aperture (§ 229).

The screens, *A* and *B*, must not be moved during the mark-

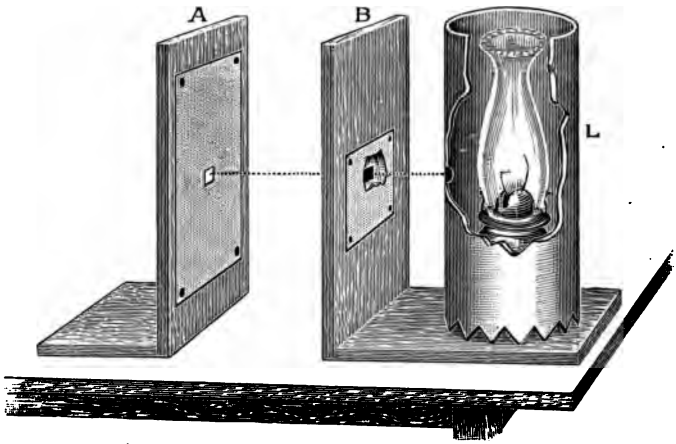


Fig. 45

ing of images. A lamp with a flat wick is necessary, and the flame must be set parallel to the screens.

Form of Tabulation. — Divide the page into two columns, *Conditions* and *Observations*. Write in the first column the successive steps taken. Opposite each describe the result. The diagram formed on the screen, *A*, is a necessary part of the record.

EXERCISE XXXII. PHOTOMETRY

Problem. — *Obtain the relative intensity of two lights.*

Apparatus. — Two **lamps**, one of which is to serve as a standard; an **optical bench**; a **photometer**. The standard lamp

has a wick about 1 cm. wide and a sheet iron chimney provided with an aperture 5 mm. in diameter opposite the center of the edge of the flame. A kerosene lamp adjusted in this manner gives a light of approximately one candle power. The photometer may be either of the Bunsen or Joly type. The lamp to be measured is surrounded by a metal cylinder provided with a large opening opposite the flame. With the lamp screened in this manner the work will not be affected by the presence of other lamps in the room.

Directions. — Darken the room. Adjust the apparatus so that the two lights are in the axis of the photometer tube (Fig. 46). Place the photometer at the center of the scale,

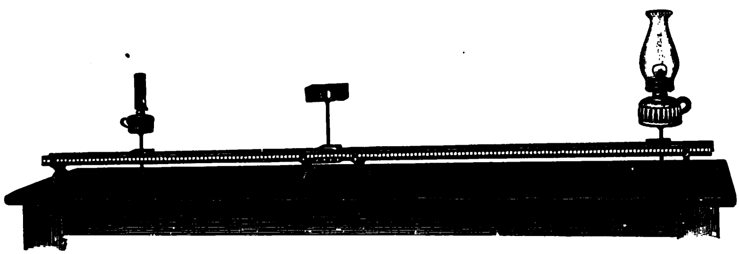


Fig. 46

the lamp on one side and the standard on the other. Move the standard to and fro until a condition of equal illumination in the photometer is secured. Record the position of the lamp, the photometer, and the standard. Compute the distance of each light from the photometer. The ratio of the squares of these distances is the relative intensity of the two lights and approximately the candle power of the lamp (§ 232).

Make several trials, placing the edge of the flame toward the photometer; also make several with the flat side. Why do they differ?

It will be found that the standard lamp can be moved a

centimeter or two before any change is detected in relative brightness. Locate the two limiting positions and enter in the record the midway position.

Form of Tabulation. — Record observations as follows: —

	Position of Lamp	Position of Photometer	Position of Standard	Distance of Lamp from Photometer	Distance of Standard from Photometer	Candle Power
	cm.	cm.	cm.	cm.	cm.	
Edge of	....	......	.....	......	......	....
Flame	....	......	.....	......	......	....
	....	......	.....	......	......	....
					Mean	....

EXERCISE XXXIII. REFLECTION

Problem. — *Verify the law of reflection of light.*

Apparatus. — A **plane mirror** mounted on a block of wood; a **protractor**; **banker's pins**.

Directions. — Fasten a leaf of the notebook on a small board with thumb tacks. Draw on it a straight line, as *MN*, and by means of the protractor erect a perpendicular, *OP*, near its middle (Fig. 47). Set the mirror with its reflecting

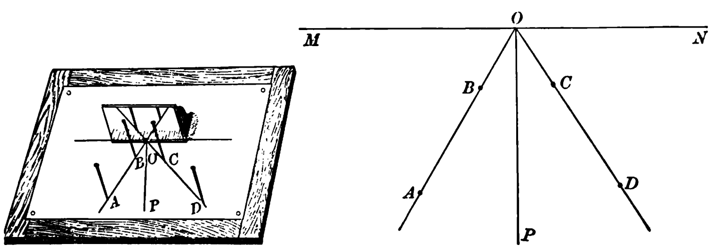


Fig. 47

surface on the line. Draw the oblique line *OA*. In this oblique line set two pins, *A* and *B*, as nearly vertical as possible. Then set two pins, *C* and *D*, in line with the images of *A* and *B* seen in the mirror. Remove the mirror and draw the straight line, *CD*. It will pass very nearly through *O* and will mark the reflection of the line, *AB*, in the mirror. Measure the angles *AOP* and *DOP*. Make several trials, varying the size of the angle *AOP*. The nearness of equality of the angles in each trial measures the accuracy of the work. A very sharp pencil must be used in drawing the lines.

Form of Tabulation. — The record comprises the figures and the following tabulation of measurements: —

	Angle of Incidence *AOP*	Angle of Reflection *DOP*	Difference
First Trial	. . . .	. . . .	. . . .
Second Trial . .	. . . .	. . . .	. . . .
etc.	etc.	etc.	etc.

EXERCISE XXXIV. ROTATING MIRROR

Problem. — *Show that a beam of light incident on a revolving mirror is displaced by reflection through an angle twice that through which the mirror is turned.*

Apparatus. — Use the same as in Exercise XXXIII.

Directions. — Fasten a leaf of the notebook on a small board with thumb tacks. Draw a straight line, *MN*, on it, and at *O* draw the oblique

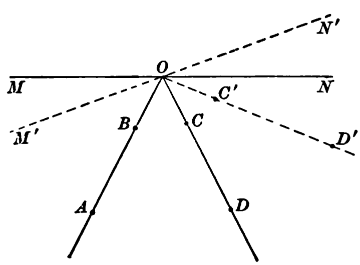


Fig. 48

line OA (Fig. 48). Place the mirror on MN; and as in Exercise XXXIII, locate the line OD. Draw through O the line $M'N'$, making with MN some definite angle, as 10°. Place the mirror on $M'N'$ and locate $C'D'$ as the reflection of OA in the mirror. Measure the angle DOD' and compare it with angle NON'. Make a second trial, giving NON' a value of 20°. The lines should be bright and narrow.

Form of Tabulation. — The record consists of the figures and the angle measurements.

	Angle of Rotation NON'	Angle of Deviation DOD'	Difference
First Trial . . .	. . . .	. . . .	. . . .
Second Trial . .	. . . .	. . . .	. . . .
Third Trial . . .	. . . .	. . . .	. . . .

EXERCISE XXXV. THE PRISM

Problem. — *Measure the angles of a triangular glass prism.*

Apparatus. — A **triangular glass prism** with its base perpendicular to its edges; **a protractor**; **banker's pins.**

Directions. — Fasten a leaf of the notebook on a small board with thumb tacks. Stand the prism on it and trace the outline of the base, ABC (Fig. 49). Draw two parallel straight lines, DE and FH, about 1 cm. apart, with the angle A between them. In DE set two pins, D and E, vertically. Now place the prism on the outline ABC. The face, BA, of the prism will act as a mirror, and the pins, E and D, can be seen in this face by reflection. Set two pins, K and L, in line with the images of D and E. In like manner, the pins, F and H, can be seen by reflection in the face, AC, of the prism. Set

the pins, *M* and *N*, in line with the images of *F* and *H*. Remove the prism and draw the lines *LK* and *MN*, intersecting

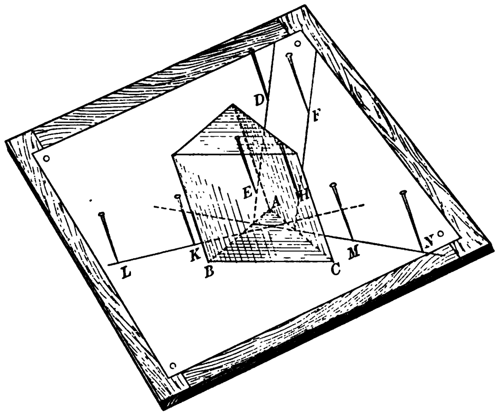


Fig. 49 (*a*)

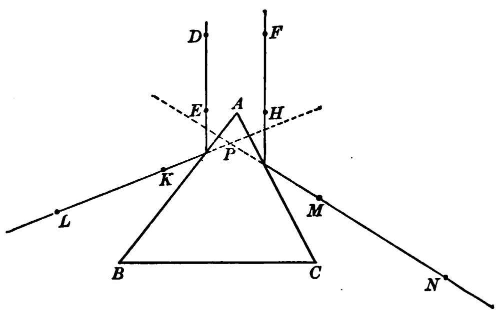


Fig. 49 (*b*)

at *P*. Measure with the protractor the angle *LPN*. Now *AB* may be considered as a mirror, and in revolving on *A* as an axis to the position *AC*, it generates the angle *BAC*. The reflection, *LK*, of the ray of light, *DE*, may be considered as

deviated by this revolution through the angle *LPN*. Therefore, the angle *LPN* is twice the angle *BAC*. Hence, measure the angle *LPN*, and take half of it for the angle *BAC*. The other angles of the prism are measured in the same manner. Make two measurements of each angle and find the average in each case. The sum of these should be 180°. Calculate the per cent of error. Draw all lines with a sharp pencil.

Form of Tabulation. — The record consists of the six figures followed by a table in which are tabulated the angles of deviation, the angles of the prism derived therefrom, the sum of the angles, the error, and the per cent of error.

EXERCISE XXXVI. IMAGES IN A PLANE MIRROR

Problem. — *Locate the position of the image in a plane mirror.*

Apparatus. — A **plane mirror** and **banker's pins.**

Directions. — Fasten a page of the notebook on a board. Draw on it a straight line *MN* (Fig. 50). Place the mirror

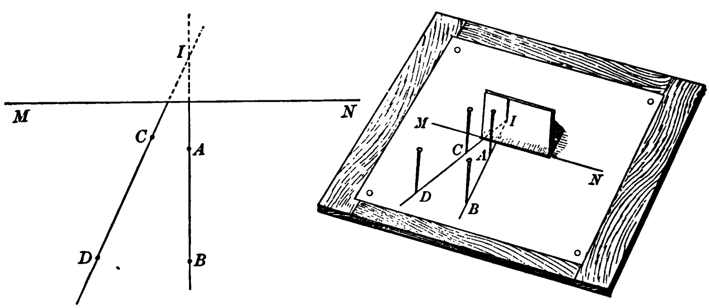


Fig. 50

on *MN* and set a pin, *A*, normally to the paper and about 5 cm. in front of the mirror. Now set a pin, *B*, in line with *A*

and its image in the mirror. In like manner, set two pins, *C* and *D*, exactly in line with the image of *A*. Remove the mirror and draw *BA* and *DC*, producing them until they meet at *I*. Measure the distances *AE* and *EI*. Make at least two trials. In the first, set *C* and *D* so that the angle *BID* is about 30°. In the second, make the angle *BID* larger, about 60°. Use a thin mirror for these two trials, and then make a third trial with a very thick mirror. Find the error in each case (§ 237). Study the conditions in these three constructions and account for the images being found nearer the mirror than the object. Greater accuracy will be secured if the pins are not set closer than 5 cm. Show by a mathematical demonstration that the image should be at the same distance from the mirror as the object.

Form of Tabulation. — The record consists of the figures and the measurements arranged in a table, as follows: —

	Distance of Object	Distance of Image	Error	Conditions
First Trial	5.4 cm.	5.1 cm.	0.3 cm.	Thin Mirror
Second Trial	6.5 cm.	6.0 cm.	0.5 cm.	Thin Mirror
Third Trial	6.3 cm.	5.6 cm.	0.7 cm.	Thick Mirror

EXERCISE XXXVII. CONCAVE MIRROR

Problem. — *Find the principal focal length of a concave spherical mirror.*

Apparatus. — A **concave spherical mirror**; an **optical bench**; a **lamp**; two small **screens**, one having a circular aperture 1.5 cm. in diameter with two threads stretched across it at right angles.

Directions. — Darken the room. Set up the apparatus as in Fig. 51. The apertured screen is placed at one end of the bench, the cross threads serving as an object in front of the mirror which is placed at the other end. The lamp is placed back of the screen to illuminate the cross threads. The second screen rests on the table with its vertical edge against the scale

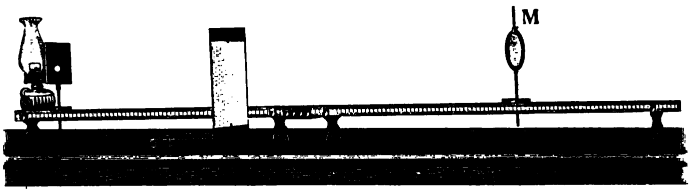


Fig. 51

on the bench for ease in reading its position. Move this screen until a sharp image of the threads is formed upon it. The mirror should be turned to bring this image near the edge of the screen touching the bench. Record the position of the object, the image, and the mirror. Calculate the distance of the object and that of the image from the mirror. Represent the former by p and the latter by q and apply the relation $f = \frac{pq}{p+q}$ (§ 246). Make several trials, varying the distance of the object from the mirror. The mean of these determinations of f is the principal focal length.

Cover the central portion of the mirror with a disk of paper and find the focal length of the rim portion. Then cover up the rim portion and find the focal length of the central part.

In the discussion, point out all the sources of error. Show by an accurately constructed diagram that the focal length of the rim rays is less than that of the central rays.

Form of Tabulation. — Enter the results as follows: —

Position of Mirror	Position of Object	Position of Image	p cm.	q cm.	f cm.	Conditions
. . . cm.	. . . cm.	. . . cm.	. .	. .	. .	Whole surface exposed
. . . cm.	. . . cm.	. . . cm.	. .	. .	. .	Whole surface exposed
. . . cm.	. . . cm.	. . . cm.	. .	. .	. .	Whole surface exposed
Mean					. .	
. . . cm.	. . . cm.	. . . cm.	. .	. .	. .	Rim exposed
. . . cm.	. . . cm.	. . . cm.	. .	. .	. .	Central part exposed

EXERCISE XXXVIII. CONVEX MIRROR

Problem. — *Find the principal focal length of a convex mirror.*

Apparatus. — A **convex lens** of about 50 cm. focal length; an **optical bench**; a **lamp**; a **convex mirror**; the **screens** of Ex. XXXVII.

Directions. — Darken the room. Place the apertured screen, *A*, near one end of the optical bench with the lamp back of it to illuminate the cross threads (Fig. 52). Place the lens, *L*, so as to give a sharp image of the cross threads on the screen,

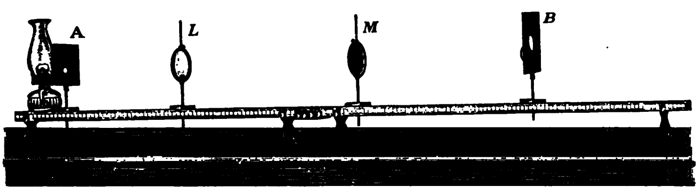


Fig. 52

B, at the other end of the bench. Insert the mirror, *M*, between *L* and *B*, finding by trial the position at which it reflects the light back on itself and gives an image of the cross threads on the screen, *A*. The mirror will do this when the rays from

the object that form the image on *B* are incident perpendicularly on the mirror. *B* is the center of curvature of the mirror under these conditions. Record the position of *M* and *B*. The difference of these readings will be the radius of curvature. Half of this radius is the principal focal length. Repeat several times with such variations in position as will prevent an exact repetition of the first readings.

Form of Tabulation. — Record the results as follows: —

Position of Mirror	Position of Image	r cm.	f cm.
. . . . cm.	. . . . cm.	. . . .	. . . .
. . . . cm.	. . . . cm.	. . . .	. . . .
. . . . cm.	. . . . cm.	. . . .	. . . .
		Mean	. . . .

EXERCISE XXXIX. IMAGES BY SPHERICAL MIRRORS

Problem. — *Study the images formed by spherical mirrors.*

Apparatus. — An **optical bench**; a **screen**; a **lamp**; a **concave mirror** of known focal length; a **convex mirror**.

Directions. — *First.* Darken the room. Mount lamp, screen, and concave mirror as shown in Fig. 53, the mirror being at one end of the bench and the lamp at the other. Move the

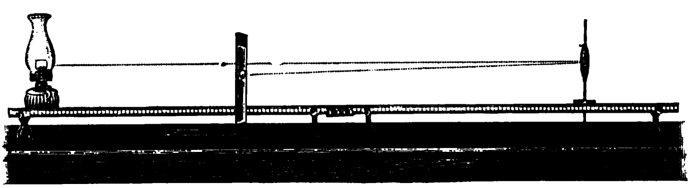


Fig. 53

screen along the edge of the bench until a sharply defined image of the lamp is seen upon it. Record the position of the mirror, lamp, and image. Calculate the distance of the lamp and that of the image from the mirror. Now determine the place of the image with respect to the center of curvature and the principal focus of the mirror. Describe the image as to kind and size.

Second. Move the lamp to the center of curvature of the mirror, locate the image, record, and describe as before.

Third. Place the lamp between the center of curvature and the principal focus, locate the image, record, and describe as before.

Fourth. Place the lamp at the principal focus and test for image as before. Explain.

Fifth. Place the lamp between the principal focus and the mirror. Locate the image. Can it be obtained on the screen? Why? At what point does the image change from real to virtual?

Sixth. Reproduce the first case. Then cover the rim of the mirror with cardboard and study the image given by the central portion as to brightness and definition. Explain.

Seventh. In like manner test the convex mirror. Does the position of the object in any manner affect the character of the image?

In discussing this problem state clearly what facts regarding images are shown in each case.

Form of Tabulation. — Record as follows: —

Case	Kind of Mirror	Focal Length	Radius of Curvature	Position of Mirror	Position of Object	Position of Image
First	Concave	. . . cm.	. . . cm.	. . . cm.	. . . cm.	. . . cm.
Second	Concave	. . . cm.	. . . cm.	. . . cm.	. . . cm.	. . . cm.
etc.	etc.	etc.	etc.	etc.	etc.	etc.

p cm.	q cm.	Place of Object with Reference to Mirror	Place of Image with Reference to Mirror	Characteristics of Image	Part of Mirror Exposed
....	....	....	....	....	....
....	....	....	....	....	....
etc.	etc.	etc.	etc.	etc.	etc.

EXERCISE XL. REFRACTION

Problem. — *Find the index of refraction of water.*

Apparatus. — A **rectangular glass tank,** $10 \times 6 \times 4$ cm. with parallel sides; a **protractor**; **banker's pins**.

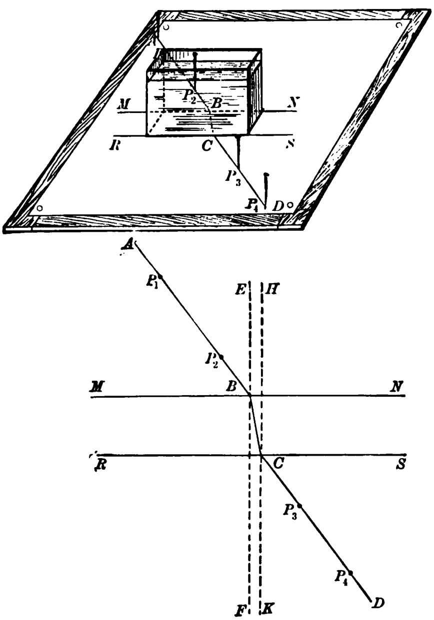


Fig. 54

Directions. — Fasten a page of the notebook on a small board. Set the glass tank upon it and draw parallel lines, *MN* and *RS*, exactly outlining two sides of its base. Draw an oblique line, as *AB* (Fig. 54). Set two pins, P_1 and P_2, in *AB* and normal to the paper. Fill the tank with water and place it exactly on the outline. Now sight through the liquid at the pins, P_1, P_2, and set the pins, P_3, P_4, exactly in line with them. Remove the tank, draw *BC*, and

with a protractor draw the perpendiculars, EF, HK. Measure the angles ABE and KCD. Record and find their mean. In like manner, measure the angles FBC and HCB and find their mean. Calculate the sines of these two mean values (App., Table VI), and divide the first by the last, carrying the division to two decimal places. This quotient is the index of refraction (§ 253). Make another trial, giving AB a different inclination.

Success depends almost wholly upon the accuracy with which the alignment of the pins is made.

The same method may be pursued for glass if a block with parallel faces is used.

Form of Tabulation. — Provide a place in which to record each angle measured, the calculated mean, the sines, and the index. The diagrams are a part of the record.

EXERCISE XLI. REFRACTION

Problem. — *Find the index of refraction of glass.*

Apparatus. — A triangular **glass prism**; **a protractor**; **banker's pins.**

Directions. — *First.* If the refracting angle of the prism is not known, it must be measured as directed in Ex. XXXV. *Second.* Fasten a leaf of the notebook on a small board and trace on it with a sharp pencil the outline of the triangular base, as BAC (Fig. 55). Set two pins, P_1 and P_3, opposite the middle of AC and AB respectively, and about 1 cm. from these faces. P_1AP_3 will form an isosceles triangle. Then set a pin, P_4, in line with P_3 and P_1 seen through the prism. In like manner, set a pin, P_2, in line with P_1 and P_3. Remove the prism and draw the lines, P_4P_3 and P_2P_1, intersecting at D. KDP_2 is the angle of deviation. Measure this angle with a protractor. If the refracting angle, BAC, is represented by a,

the deviation, KDP_2, by d, the index of refraction, μ (mu), is found by the relation $\mu = \frac{\sin \frac{1}{2}(a + d)}{\sin \frac{1}{2} a}$. To use this relation, add together the mean value found for a and the mean of the values obtained for d, and find the sine of half of this sum (App., Table VI). In like manner, find the sine of half of a.

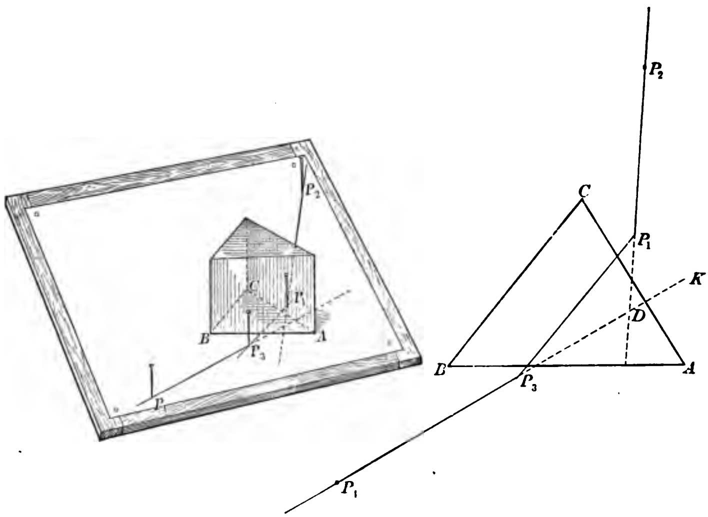


Fig. 55

The quotient of the former by the latter is the index of refraction.

The chief difficulty in this problem is in obtaining accurate alignments on account of the dimness of P_1 and P_3, as seen through the prism.

Form of Tabulation. — Record the different trials, the mean values, the sines, the index. The diagrams are a part of the record.

EXERCISE XLII. THE CONVEX LENS

Problem. — *Measure the focal length of a convex lens.*

Apparatus. — An optical bench; a lamp: the screens of Ex. XXXVII; a convex lens.

Directions. — Darken the room. Set up the apparatus as shown in Fig. 56. Find by trial a position for the lens and image screen, such that a clearly defined image of the cross threads is obtained on the image screen. Record the position

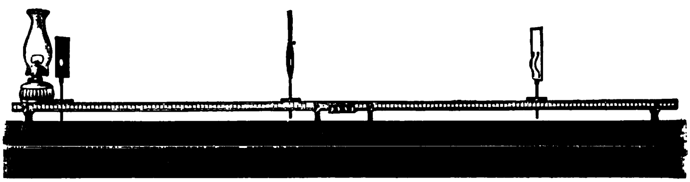


Fig. 56

of each screen and that of the lens. Calculate the distance of the object and that of the image from the lens. Represent the former by p and the latter by q, and calculate f by the relation $f = \frac{pq}{p+q}$ (§ 268). Give the lens different positions to vary the values of p and q and calculate f. The mean of these results is the focal length of the lens.

Cover the rim of the lens with a piece of cardboard in which there is cut a circular opening whose diameter is two thirds that of the lens. This will expose the central part of the lens. Find f for the central rays. Then cover the central part and find f for the rim rays. Compare these values with that for the whole surface.

Form of Tabulation. — Similar to that of Ex. XXXVII.

EXERCISE XLIII. THE CONCAVE LENS

Problem. — *Measure the principal focal length of a concave lens.*

Apparatus. — The same as that of Ex. XLII; a **concave lens.**

Directions. — Darken the room. Place the lamp, apertured screen, convex lens, image screen on the optical bench in the

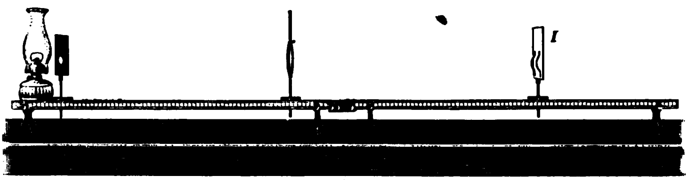


Fig. 57

order named, and adjust until a sharply defined image of the cross threads is obtained, the object being nearer the lens than the image (Fig. 57). Record the position of the image, *I*. Now insert the concave lens between the convex lens and the image, *I* (Fig. 58), just found, move the image screen back un-

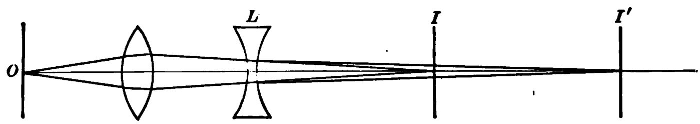


Fig. 58

til a sharply defined image is again obtained. Record this second position of the image, *I'*, and also the position of the concave lens, *L*. A study of Fig. 58 shows that light emitted from *I* would issue from the lens, *L*, as if it came from *I'*; that is, *I* and *I'* are conjugate foci to the lens, *L*. Calculate the distance of *I* and *I'* from *L*. These will be *p* and *q* of the lens formula $f = \frac{pq}{p - q}$ (§ 268). Substituting in this formula the

values of p and q, the value of f is found. Why is it negative? In repeating the work change the position of the convex lens.

Form of Tabulation. — Provide for the position of the lens, the first image screen, the second image screen, and the distances p, q, and f.

EXERCISE XLIV. IMAGES BY LENSES

Problem. — *Study the images formed by lenses.*

Apparatus. — The same as in Ex. XLIII.

Directions. — Darken the room. Place the lamp, convex lens, and screen on the optical bench in the order named (Fig. 59).

First. Place the lamp away from the lens more than twice the focal distance of the lens and locate the image. Record the position of the object, lens, and image. Calculate the

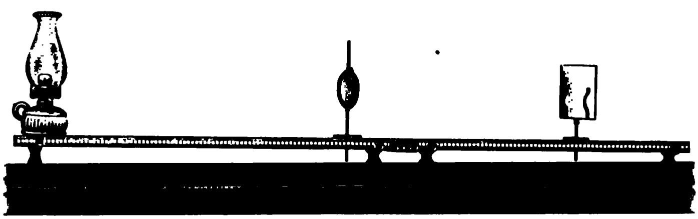


Fig. 59

distance of the object from the lens, and also that of the image. Describe the image as to size, character, and position.

Second. Place the lamp at twice the focal distance from the lens and proceed as before.

Third. Place the lamp at a distance from the lens less than twice and more than once the focal length of the lens and proceed as before.

Fourth. Place the lamp at the focus of the lens and describe the image.

Fifth. Place the lamp between the principal focus and the lens and describe the image.

Sixth. Reproduce the second case and compare the effect on the image of covering up the rim of the lens.

Seventh. Substitute the concave lens for the convex lens and study the images. Ascertain if the position of the object influences the character of the image.

In discussing the work, point out what each case shows regarding images.

Form of Tabulation. — Record the observations in the same manner as directed in Ex. XXXIX.

EXERCISE XLV. THE MICROSCOPE

Problem. — *Make a compound microscope out of two convex lenses.*

Apparatus. — An **optical bench**; a small **lamp**; a **screen**; a **convex lens** of about 5 cm. focus; a **convex lens** of about 25 cm. focus.

Directions. — Darken the room. Support the lamp and the lens of shorter focus on the optical bench, adjusting them to give an enlarged image of the lamp on the screen. Now place the lens of longer focus on the bench so that the image screen is between it and its principal focus (§ 270). Now remove the screen and look through the lenses at the lamp. An enlarged inverted image of the lamp will be seen. It may need a little adjusting of the lens next to the eye for distinct vision. What is the office of the lens of short focus? Of the other? Substitute a lens of longer focus for the one next the object and note the effect. Substitute a lens of shorter focus for the one

next to the eye and note the effect. Upon what does the magnifying power depend?

Form of Record. — Make a narrative account of what was attempted and the degree of success.

EXERCISE XLVI. THE TELESCOPE

Problem. — *Make a telescope out of two convex lenses.*

Apparatus. — An **optical bench**; a large **convex lens** of about 50 cm. focus; a **convex lens** of about 10 cm. focus; a **screen**; a **lamp**.

Directions. — Darken the room. Place the lens of longer focal length at the end of the optical bench. Place the lamp about five meters distant and in line with the bench. Find the image of the lamp on the screen. The adjustments should be such that the screen will be on the bench. Set the second lens on the bench so that the image just formed will be between this lens and its principal focus (§ 271). Remove the screen and look through the lenses at the lamp. A large inverted image of the lamp will be seen. A slight adjustment of the lens may be necessary for distinct vision. Try the effect of a lens of shorter focus for the eyepiece. What is the office of each lens?

Form of Tabulation. — See Ex. XLV.

EXERCISE XLVII. THE OPERA GLASS

Problem. — *Make a telescope out of two lenses, one of which is concave and the other is convex.*

Apparatus. — An **optical bench**; a **convex lens** of about 50 cm. focus; a **concave lens** of about 15 cm. focus; a **lamp**; a **screen**.

Directions. — Darken the room. Arrange the lamp, convex lens, and screen as in Ex. XLVI. Support the concave lens between the screen and convex lens with its focus near the screen but between it and the convex lens (§ 272). Remove the screen and look through the lenses at the lamp. An erect image of the lamp will be seen. It may be necessary to adjust the concave lens to secure good definition. Wherein do the results differ from those of Ex. XLVI? Compare the distance between the lenses in this case with that of Ex. XLVI.

Form of Tabulation. — See Ex. XLV.

CHAPTER VII

HEAT

EXERCISE XLVIII. THE THERMOMETER

Problem. — *Test the accuracy of the location of the fixed points on a thermometer, and construct a table of corrections.*

Apparatus. — A 4-inch **glass funnel**; a **steam generator**; a wide-mouthed quart **bottle**; a **centigrade thermometer.**

Directions. — *First.* Support the thermometer in the funnel and pack ice shavings around it as far up as the zero of the scale (Fig. 60). After the lapse of ten minutes, read the thermometer by the aid of a magnifier, estimating fractions of a degree in tenths. If the reading is above zero, record it as +, if below, as −. Subtract the reading from zero for the correction. This will be the quantity to be added to the observed freezing point to give the true freezing point.

Fig. 60

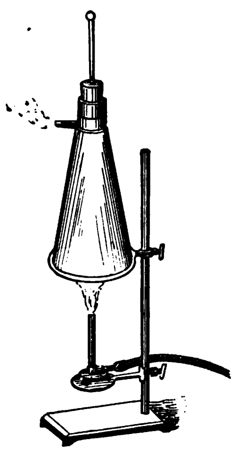


Fig. 61

Second. Test the boiling point by supporting the thermometer within the steam generator (Fig. 61), the bulb not nearer to the water than perhaps 3 cm. After the water has been boiling for ten minutes, take the reading. The barometer should also be read at this time. The

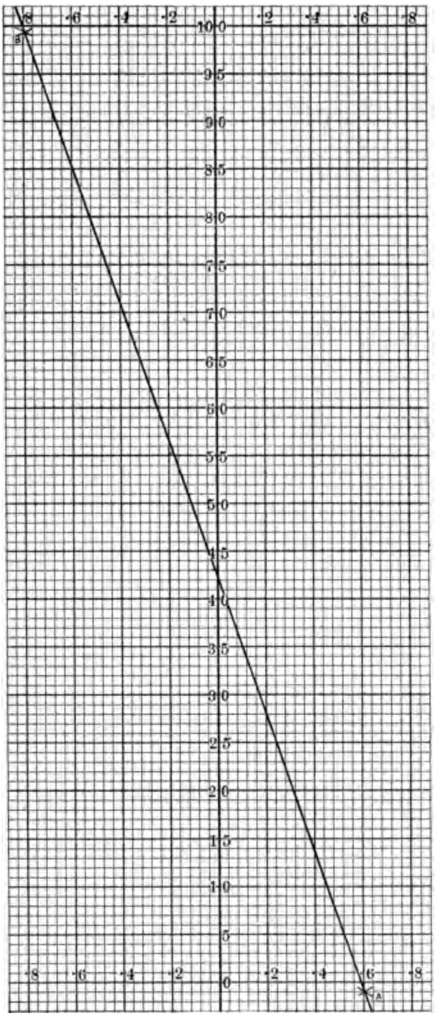


Fig. 62

true boiling point is found by the following relation, $t = 100° - 0°.0375\,(760 - b)$, in which b is the barometer reading expressed in mm. Subtract the observed boiling point from the true boiling point for the correction. To illustrate: if the barometer pressure is 742 mm., the true boiling point is $100° - 0°.0375\,(760 - 742) = 99°.3$. If the observed boiling point is 100°.1, then the correction is $99.3 - 100.1 = -0°.8$.

Third. To construct a table of corrections, proceed as follows: Draw on a sheet of cross-section paper a straight line to represent the thermometer, and lay off on it the thermometer scale as shown in Fig. 62. To the right of the line lay off a scale for positive corrections, and to the left for negative. If the correction for the

freezing point, for example, is $+0°.6$, then on the horizontal line -0.6 lay off to the right $+0.6$, giving the point A. If the correction for the observed boiling point, $100°.1$, is $-0°.8$, then on the horizontal line 100.1 lay off to the left -0.8, giving the point B. Draw a straight line through A and B. The correction for any thermometer reading will be the distance of the point on the thermometer scale from AB measured by the scale of the drawing. For points having the correction line to the right, the correction is positive; and for those to the left, negative.

Make the table of corrections to include readings from 0° to 100° by intervals of 5°.

Form of Tabulation. — The following example illustrates the method: —

CENTIGRADE THERMOMETER No. 5

	FREEZING POINT	BOILING POINT	BAROMETER PRESSURE
Observed	− 0°.6	100°.1	742 mm.
True	0	99 .3	
Correction	+ 0 .6	− 0 .8	

TABLE OF CORRECTIONS

READING	CORRECTION	READING	CORRECTION	READING	CORRECTION
0°	0°.59	35°	0°.10	70°	− 0°.39
5	0 .52	40	0 .03	75	− 0 .46
10	0 .45	45	− 0 .02	80	− 0 .53
15	0 .37	50	− 0 .11	85	− 0 .60
20	0 .31	55	− 0 .18	90	− 0 .67
25	0 .24	60	− 0 .25	95	− 0 .74
30	0 .17	65	− 0 .32	100	− 0 .81

EXERCISE XLIX. EXPANSION

Problem. — *Determine the coefficient of expansion of a metal rod.*

Apparatus. — A **steam generator**; a **thermometer**; a **metal tube**, 75 cm. long, with a stout pin passing through it normally at about 10 cm. from one end, and projecting 2 cm. on each side, and a second pin soldered to the outer wall near the

Fig. 63

other end of the tube; a **wire micrometer** clamped to the frame that supports the tube (Fig. 63).

Directions. — Measure to the nearest millimeter the distance between the two pins and record this as the length of the tube. Attach a funnel to the tube by a short rubber tube; fill it full of cold water and let it stand for five minutes. Turn the micrometer head until the screw touches the pin and record the reading. Now turn the screw back three complete revolu-

tions, empty the tube and connect it to the steam generator. The temperature of the water that was in the tube is to be taken and recorded as the initial temperature of the tube. Pass steam through the tube freely for ten minutes, then turn the head of the micrometer until contact with the pin is secured, and record the reading. Suspend a thermometer in the steam generator for several minutes and record the temperature of the steam. This temperature may be taken as that of the tube. The difference between the two micrometer readings will be the expansion of the tube. This expansion, divided by the difference between the two temperature readings, will be the expansion for one degree. This expansion for one degree divided by the length of the tube will be the coefficient of expansion (§ 311).

To repeat the work, cool the tube by filling it with cold water, and then proceed as before.

It is advisable to cover the base of the supporting frame with asbestos paper to protect it from the heat radiating from the tube and causing it to expand.

Calculate the coefficient for each set of data obtained and take the average. Compare this mean value with that given in the Table of Coefficients of Expansion (App., Table III), and compute the per cent of error.

Form of Tabulation. — Record the observations as follows: —

Material	Length	Initial Temperature	Final Temperature	First Micrometer Reading	Second Micrometer Reading	Coefficient of Expansion	Accepted Coefficient	Per Cent of Error
	cm.		mm.	mm.	mm.			
. . .	. . .	. . . .	. . . .	. . . .	. . . .	. . . .		
		. . . .	. . . .	. . . .	. . . .	. . . .		
					Mean	. . . .	. . . .	. . . .

EXERCISE L. EXPANSION

Problem. — *Find the coefficient of expansion of mercury.*

Apparatus. — A **glass tube** with a bulb of 5 cm.^{3} capacity on one end, the stem being graduated; a glass **jacket**; a **thermometer**; a **steam generator.**

Directions. — Set up the apparatus as shown in Fig. 64. Fill the graduated tube with mercury part way up the stem. Slip a short piece of rubber tubing over the stem of the jacket and apply a pinchcock. Fill the jacket with ice water, and after ten minutes read the thermometer and the volume of the mercury. Now draw off the water, leave the tube open, and pass steam from the generator through the jacket. After the steam has been passing freely for ten minutes, read the temperature and the volume of the mercury. The difference between the two volume readings will be the expansion. This expansion divided by the difference of the two temperature readings will be the expansion for one degree. This expansion for one degree divided by the first volume reading will be the apparent coefficient of expansion. Since the glass tube expanded, it reduced the apparent expansion of the mercury. Hence the apparent coefficient must be increased by the coefficient of glass 0.0000258, to give the true coefficient (§ 311).

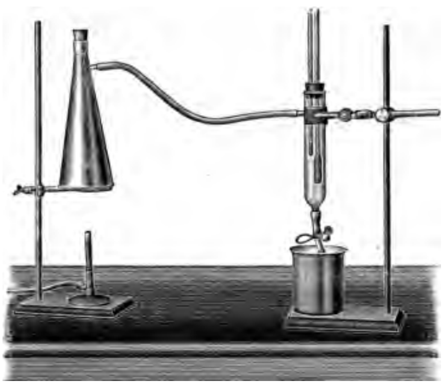


Fig. 64

Repeat the work, calculate the mean, compare with the coefficient given in the Table of Coefficients of Expansion (App., Table III) and calculate the per cent of error.

Form of Tabulation. — Record the observations as follows: —

Liquid	Initial Volume	Final Volume	Initial Temperature	Final Temperature	Apparent Coefficient	Corrected Coefficient	Accepted Coefficient	Per Cent of Error
	cm.^{3}	cm.^{3}						
. .	. . . .	. . . .	. . . . .	. . . .	. . . . .	. . . . .	. . . . .	. . .
. .	. . . .	. . . .	. . . . .	. . . .	. . . . .	. . . . .		
					Mean	. . . . .		

EXERCISE LI. SPECIFIC HEAT

Problem. — *Find the specific heat of a metal.*

Apparatus. — A **metal cylinder**, about 2.5 cm. long by 2 cm. diameter, to which is attached a fine wire for handling; a **nickel-plated beaker** of 250 cm.^{3} capacity for a calorimeter (Fig. 65); a **thermometer**; a **copper beaker** in which to heat the cylinder; an **iron ring stand**; a **balance**; a **box of weights**.

Fig. 65

Directions. — Weigh the nickel-plated beaker empty and also half full of water at a temperature of about two degrees below that of the room. Weigh the cylinder and then heat it in a beaker of water to about 60° C. Now take the exact temperature of the water that was weighed. Remove the beaker of hot water from the iron stand and then take its exact temperature to obtain the temperature of the metal cylinder. Transfer the cylinder to the calorimeter, wiping off any drops of water

adhering. Keep moving the cylinder about in the water of the calorimeter to equalize the temperature. Insert the thermometer and note carefully the highest temperature obtained. The chief mistake of the problem will be at this point, in not getting the temperature unified before taking the reading. Water is a poor conductor of heat, and a region near the cylinder may be at a higher temperature than one more remote unless the stirring is well done. The thermometer should read the same when near the cylinder as when near the side of the calorimeter.

It should be observed that not only does the temperature of the water rise, but also that of the calorimeter rises. Hence, the water equivalent of the calorimeter must be calculated and added to the water in the calorimeter. To obtain the water equivalent, multiply the mass of the calorimeter by the specific heat of the material composing it (App., Table IV). This total quantity of water multiplied by its increase in temperature will be the amount of heat gained by the water. The heat lost by the cylinder will be the product of its mass, its specific heat, and its loss of temperature (§ 320). These two products are equal and form an equation with specific heat for the unknown quantity. By solving the equation the specific heat is obtained.

An approximate correction is made for radiation by giving the water in the calorimeter a temperature a little below that of the room before introducing the heated cylinder. Then the room heats the water during the first part of the gain of temperature and loses to the room during the last part. These will nearly offset each other. The experiment should be repeated several times, the mean obtained, and the per cent of error calculated. Do not touch the calorimeter with the hand during the progress of the experiment and shield it from radiation from the Bunsen burner. In the discussion explain the successive steps in the calculation.

Form of Tabulation. — Record the observations as follows: —

Substance	Temperature of Room	Mass of Calorimeter	Mass of Cylinder	Mass of Calorimeter and Water	Temperature of Cylinder	Initial Temperature of Water	Final Temperature of Water	Specific Heat	Accepted Value	Per Cent of Error
. . .	. . .	. . gm.	. . gm.	. . gm.	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . gm.	. . gm.	. . gm.	. . .	. . .	. . .	. . .		
							Mean	. . .		

EXERCISE LII. FUSION

Problem. — *Determine the heat of fusion of water.*

Apparatus. — A **calorimeter**; a **thermometer**; a **balance**; a **box of weights.**

Directions. — Weigh the calorimeter and compute its water equivalent. Fill it two thirds full of water at about 40° C. and weigh it. Then take the exact temperature of the water, after which add clean, dry ice in pieces as large as hickory nuts, sufficient, when melted, to lower the temperature of the water in the calorimeter to a point as far below the temperature of the room as the water was above at the beginning. Dry the ice with a cloth before introducing it into the calorimeter. A preliminary trial may be necessary in order to determine approximately the amount of ice necessary. As soon as the ice is melted, stir the water thoroughly with the thermometer, note the temperature, and then find the weight.

The difference between the two weighings will be the amount of ice melted, and the first weight less the weight of the calorimeter will be the amount of water used. The heat lost by the calorimeter and its contents will be the mass of water increased by the water equivalent of the calorimeter,

multiplied by the difference between the initial temperature and the final. The heat gained by the ice will be the mass of ice multiplied by the heat of fusion, or l, plus the heat required to raise the ice water from zero to the final temperature, or the mass of ice multiplied by the final temperature (§ 324). Placing the heat lost equal to the heat gained and solving for l gives the heat of fusion. Make several trials, find the mean, and calculate the per cent of error. In the discussion explain the process of calculating the heat of fusion.

Form of Tabulation. — Record the results as follows: —

Temperature of Room	Mass of Calorimeter	Mass of Water and Calorimeter	Mass of Water	Mass of Water Cor'd for Water Equivalent	Initial Temperature	Final Temperature	Mass of Water and Calorimeter at End	Mass of Ice	Heat of Fusion	Accepted Value	Per Cent of Error
. .	. . gm.	. . gm.	. . gm.	. . gm.	. .	. .	. . gm.	. . gm.	. .	. .	. .
. .	. . gm.	. . gm.	. . gm.	. . gm.	. .	. .	. . gm.	. . gm.	. .		
								Mean	. .		

EXERCISE LIII. VAPORIZATION

Problem. — *Determine the heat of vaporization of water.*

Apparatus. — A **steam generator**; a **water trap** (Fig. 66); a **calorimeter**; a **thermometer**.

Directions. — Set up the apparatus as shown in Fig. 67. Weigh the calorimeter and compute the water equivalent. Fill it two thirds full of water at a temperature of about 10° below that of the room and find the mass. After weighing the water take its exact temperature and then immediately introduce steam from the generator. Stir the water constantly with the thermometer while admitting steam. When the temperature of

the water has risen nearly to 10° above that of the room, stop admitting steam. Then stir the water thoroughly for a moment before taking its temperature. Now weigh the calorimeter and its contents. The increase in mass will be the amount of steam introduced. Suspend the thermometer in the generator and obtain the temperature of the steam.

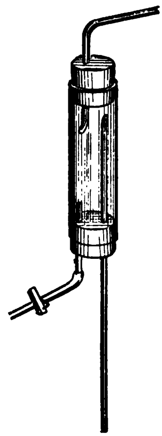


Fig. 66

The heat lost by the steam will be the mass of steam multiplied by the heat of vaporization, or L, plus the heat lost by the steam water in cooling from the boiling point to the final temperature. The heat lost by the steam water is the product of the amount of steam by the difference between the temperature of the steam and the final temperature. The heat gained by the water will be the mass of water at first, increased by the water equivalent of the calorimeter, multiplied by the water's gain of temperature (§ 332). Place these two quantities equal and solve for L, the heat of vaporization. Make several trials, find the mean, and calculate the per cent of error. The water trap is designed to collect any condensation that takes place in the delivery tube. When the trap is full of water, it is emptied by opening the

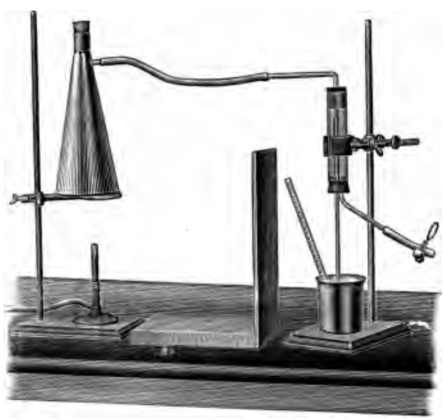


Fig. 67

pinchcock on the tube at the bottom. In the discussion explain all the calculations made.

Form of Tabulation. — Record the results as follows: —

Temperature of Room	Mass of Calorimeter	Mass of Water and Calorimeter	Mass of Water Corrected for Calorimeter	Initial Temperature	Final Temperature	Mass of Water, Calorimeter and Steam	Heat of Vaporization	Accepted Value	Per Cent of Error
. .	. . gm.	. . gm.	. . . gm.	. .	. .	. . gm.	. . .	. .	. .
. .	. . gm.	. . gm.	. . . gm.	. .	. .	. . gm.	. . .		
						Mean	. . .		

EXERCISE LIV. HUMIDITY

Problem. — *Determine the dew point and from it calculate the humidity of the room.*

Apparatus. — A polished **nickel-plated beaker,** 250 cm.^{3} capacity; a **thermometer**; **ice.**

Directions. — Fill the beaker half full of water at the temperature of the room. Add a few small pieces of ice and stir gently with a thermometer. Support a clean sheet of glass so as to prevent breathing on the beaker. As soon as a mist is seen to collect on the mirror surface of the beaker take the temperature of the water. Then remove the ice and note the temperature of the water when the mist disappears. The mean of these two temperatures may be considered as the dew point. Find the average of two or three trials.

Obtain the temperature of the room from a thermometer supported on the table near where the experiment is being carried on. Find from Table V of the Appendix the pressure of the aqueous vapor at the temperature of the dew point just

found. Also find the pressure for the temperature of the room. The ratio of these pressures is the relative humidity (§ 333).

Form of Tabulation. — Record the observations as follows: —

Temperature on Appearance of Mist	Temperature on Disappearance of Mist	Dew Point	Humidity
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	
	Mean . . .	. . . .	

CHAPTER VIII

MAGNETISM

EXERCISE LV. MAGNETIC SUBSTANCES

Problem. — *Separate a number of metallic objects into two groups, magnetic and non-magnetic.*

Apparatus. — A **bar magnet**; a **collection** of small metallic bodies each marked with a number.

Directions. — Apply the bar magnet to each object in succession. Those that the magnet attracts are magnetic; the others are probably non-magnetic. Greater accuracy is secured by using a more powerful magnet.

Form of Tabulation. — Record the observations as follows: —

NUMBER	SUBSTANCE	EFFECT OF MAGNET ON IT	INFERENCE
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .

EXERCISE LVI. FIRST LAW OF MAGNETISM

Problem. — *Determine the law of magnetic action.*

Apparatus. — Two **bar magnets** with marked poles; a **stirrup** of copper or brass wire; a **wooden support.**

Directions. — Suspend one of the bar magnets in the stirrup by an untwisted thread (Fig. 68), and let it come to rest.

Describe its position. Now bring the north pole of the second magnet slowly to the north pole of the suspended one. Record the effect. In like manner bring the south pole of the second one to the south pole of the suspended one and note the effect. Finally bring the south pole of the second one to the north pole of the suspended one and note the effect. Summarize these observations into a concise law. How would you apply the law to determine the poles of an unmarked magnet?

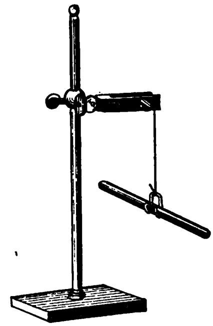


Fig. 68

Form of Tabulation. — Record the work as *Conditions* and *Observations.* Under the first head record what test is made in each case, and under *Observations* describe briefly what took place.

EXERCISE LVII. POLARITY

Problem. — *Locate the poles of a bar magnet.*

Apparatus. — A **bar magnet**; a **compass**; a small **board**; **banker's pins.**

Directions. — Place a sheet of the notebook on the board and trace on it an exact outline of the bar magnet. Mark with + the north end. Place the compass on the paper near one corner of the north end of the magnet (Fig. 69). Turn the board until

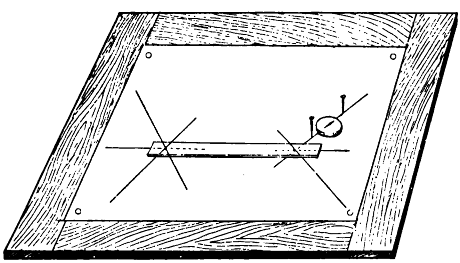


Fig. 69

the compass needle points north and south; then set vertically two pins, one on each side of the compass, exactly in line with the magnetic axis of the needle. Move the compass to the adjoining corner of the magnet and proceed as before. Then move the compass opposite the end of the magnet and proceed as before. Draw straight lines with a sharp pencil through the points marked by the pins. These lines intersect either in a common point or more probably so as to inclose a small area. The point or small area may be considered as the north pole of the magnet. In like manner locate the south pole.

What effect would it have on the result if the north pole of the bar magnet pointed constantly to the north throughout the work? What if it pointed south? What if it pointed west?

Form of Tabulation. — The record will be the diagram obtained.

EXERCISE LVIII. MAGNETIC STRENGTH

Problem. — *Compare the strength of the two poles of a bar magnet.*

Apparatus. — A bar magnet; a box of iron tacks.

Directions. — Since the two ends of a bar magnet are of the same shape and size, their magnetic strengths may be compared by finding how many tacks each will lift. To do this, place the tacks in a small box or beaker. Insert the north pole into the box and count the number of tacks lifted out. Repeat the process several times and average the results. In like manner test the south pole. Divide the average number of tacks lifted by the north pole by that lifted by the south pole. The quotient will be their relative strengths.

In the successive trials it is very important to introduce

the magnet into the tacks as nearly under the same conditions as possible.

Form of Tabulation. — Record the results as follows: —

	Number of Tacks Lifted by		Ratio of N to S
	North End	South End	
First Trial	. . . .	. . . .	
Second Trial . .	. . . .	. . . .	
etc.			
Mean	. . . .	. . . .	. . . .

EXERCISE LIX. MAGNETIC DISTRIBUTION

Problem. — *Determine the distribution of the magnetism in a bar magnet and represent the results by a graph.*

Apparatus. — A **magnetized steel rod**, 14 cm. long by 3 mm. in diameter; a **clamp support**; a **watch**; a **magnetoscope.**

Directions. — By means of the screw at the top of the magnetoscope adjust the needle to north and south. Now by bringing a magnet near it, set the needle vibrating through a small arc and count the number of vibrations in 30 sec. Do this at least three times and find the mean. This number represents the strength of the earth's magnetic field at that place, provided no magnet is near. Mark off the slender magnet into seven equal parts and bisect the two parts at each end. There will then be twelve points on the magnet including the ends. Support the magnet vertically (Fig. 70), with its south pole on the

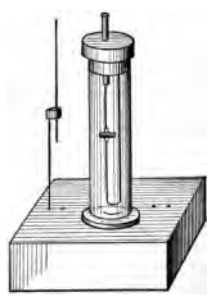


Fig. 70

north side of the magnetoscope, and as close as practical to the glass case of the magnetoscope. Adjust the height of the magnet until the axis of the magnetoscope needle passes through its south end point.

Now set the needle vibrating as before and count the number of vibrations in 30 sec. Make at least three counts and find the mean. Adjust the magnet so that the axis of the needle passes through the second point from the south end of the magnet, keeping the magnet at the same distance from the magnetoscope as at first, and find the number of vibrations of the needle as before. Proceed in this manner for each of the twelve points. When the number of vibrations of the magnetoscope is less than the number made under the earth's action alone, the magnet must be shifted to the south side of the magnetoscope to complete the tests. This may occur on either side of the middle of the magnet.

The magnetoscope conforms to the law of the pendulum, and the magnetic force actuating it varies as the square of the number of vibrations; that is, $H \propto n^2$, in which H represents the earth's force and n the number of vibrations due to the earth. When the magnet is placed near the magnetoscope, H is increased by F, the force of the magnet, and $(F+H) \propto N^2$, in which N is the number of vibrations due to these combined forces. Then, if $H \propto n^2$ and $(F+H) \propto N^2$, it follows that $F \propto N^2 - n^2$; that is, to obtain a measure of the force of the magnet, subtract the square of the number of vibrations due to the earth alone from the square of the number due to the earth and the magnet combined.

To represent the data graphically, draw a heavy straight line 14 cm. long, lengthwise of the middle of a sheet of cross-section paper. Mark the top end, N, and the bottom end, S. Lay off on this line the twelve points tested, spacing them as on the magnet, the five points at either end being 1 cm. apart and the four middle ones 2 cm. apart. Lay off a scale at the

top and also at the bottom of the page, the zero being on the magnet line, the scale extending both to the left and to the right. Each centimeter of the paper may represent 50, 100, 150, or 200, as may be necessary to bring the points plotted on the page. Plot the numbers for the north end on the right side of the line and the others on the left. Now locate points on the page such that their distances from the magnet line, as determined by the scale adopted, will be the magnetic strength at these points. Sketch a smooth curve through these points. The poles will be indicated by the parts of the curve farthest from the magnet line; the magnetic equator will be the point of intersection of the curve with the magnet line.

Form of Tabulation. — The following plan of recording the data is recommended: —

	Earth	North End						South End					
		1	2	3	4	5	6	7	8	9	10	11	12
First count . . .	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Second count . .	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Third count . . .	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Mean	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Numbers squared	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Relative strength	. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .

EXERCISE LX. MAGNETIC FIELDS

Problem. — *Map the magnetic field of a bar magnet, (a) eliminating the earth's influence; (b) not eliminating the earth's influence.*

Apparatus. — A **bar magnet**, 10 cm. long; a **magnetic needle**, 15 mm. long, mounted on a support 1 cm. high; a **board** 30 cm. square.

Directions. — Fasten an unruled page of the notebook on the board, using brass tacks for the purpose. Place the magnet at the middle of the page and trace its outline. Near the north end of the magnet place the small mounted needle, turn the board until the needle points to the north, and mark with a sharp pencil two points, one at each end of the needle. Move the needle away from the magnet until its south end is exactly over the previously marked north end after turning the board sufficiently to make the needle point north. Proceed in this manner until the south pole of the magnet is reached. A line drawn through these points maps out a line of force. The influence of the earth has been eliminated by keeping the needle in the magnetic meridian. In this manner trace a line from each corner of the magnet, from the middle of each end, and from a point on each side, 1 cm. in from the end. The lines from the sides will curve around to the magnet, those from the ends will probably run off the paper before doing so. Hence those from the ends need not be carried out farther than 6 cm. from the magnet.

On a second sheet of paper repeat the work with this difference, the board is not rotated and the north end of the magnet points to the west throughout the work.

The record will consist of the two diagrams properly designated and the discussion should be a comparison of the two figures in which any differences are pointed out and explained.

EXERCISE LXI. MAGNETIC SPECTRA

Problem. — *Obtain by photography a picture of the following cases of magnetic fields as mapped out by iron filings: (a) a single bar magnet; (b) two similar bar magnets placed parallel with like poles adjacent; (c) two similar bar magnets placed parallel with unlike poles adjacent; (d) the end of a bar magnet.*

Apparatus. — Two **similar bar magnets**, 7.5 cm. long; **iron**

filings; **blue-print paper,** "extra quick" quality; a **plate of glass** 25 cm. square.

Directions. — Lay the magnet or magnets on the table in the desired position, and place the plate of glass over them. Sift the iron filings evenly over the glass and tap it gently to assist the filings in moving under the directive force of the magnet. Lift the glass from the magnet, place it on a sheet of blue-print paper supported on a board, and expose it for the requisite time to either sunlight or an electric arc light. When sufficiently printed, wash thoroughly in water and dry.

The record will consist of the four figures, properly distinguished. The discussion should be a comparative description of the figures.

CHAPTER IX

ELECTRICITY

EXERCISE LXII. ELECTROSCOPE

Problem. — *Charge an electroscope, (a) positively, (b) negatively, by means of a glass rod and a silk pad.*

Apparatus. — An **electroscope** (Fig. 71); a **rod of flint glass,** 30 cm. long; a **silk pad**; a **proof plane** (Fig. 72).

Directions. — *First.* To charge the electroscope positively, rub the glass rod with the silk, apply the ball of the proof plane

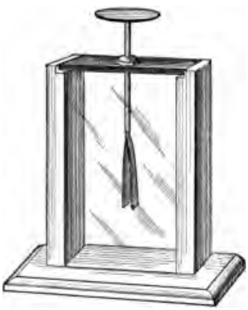


Fig. 71

Fig. 72

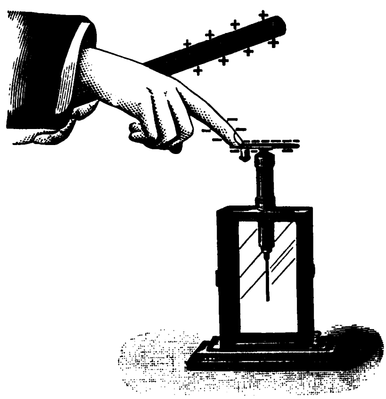


Fig. 73

to it, and then touch the disk of the electroscope with it. The leaves of the electroscope will become positively charged (Why ?) and will separate (Why ?).

Second. To charge the electroscope negatively, electrify the glass rod as before and hold it a few centimeters above the disk of the electroscope (Fig. 73); at the same time touch the disk with the finger. Remove the finger and then remove the electrified rod. The electroscope will now be negatively charged. Why? Prove that it is negatively charged. Ascertain the effect on the intensity of the charge to hold the rod farther away from the disk; also that of holding it nearer.

In recording the work, state in narrative form what was accomplished in each case.

EXERCISE LXIII. ELECTRIFICATION

Problem.— *Test a body for electrification and determine the kind.*

Apparatus. — An **electroscope**; a **flint glass rod**; a **silk pad**; a **proof plane**; a **piece of fur**.

Directions. — Give the electroscope a feeble positive charge (How?). Rub a sheet of paper with fur and take a charge from the paper with the proof plane and give it to the electroscope. If the divergence of the leaves is increased, then the paper is charged positively. If the divergence is diminished, then give the electroscope a feeble negative charge (How?), and proceed as before. The leaves should now diverge farther, showing the charge to be negative.

Try other substances, such as hard rubber excited with fur, silk excited with fur, leather excited with flannel, etc.

Form of Tabulation. — Record the results as follows: —

Substance	Rubbed with	Behavior of + Charged Electroscope	Behavior of − Charged Electroscope	Inference
. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . .
. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . .

EXERCISE LXIV. MAGNETIC EFFECT OF ELECTRIC CURRENT

Problem. — *Determine the law expressing the effect of the electric current on a magnetic needle.*

Apparatus. — A **dry cell**; a **contact key**; a **pocket compass**; a meter of insulated **copper wire**, No. 20, for connections; a **block** in which to place the compass; a meter of **annunciator wire**, No. 24.

Directions. — Set up the apparatus as shown in Fig. 74. The insulation must be removed from the ends of the wires before

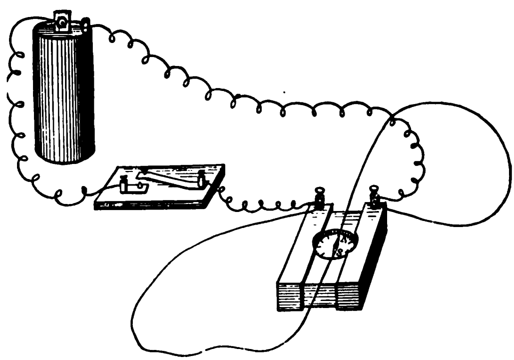


Fig. 74

insertion in the binding posts. Why? The flexible annunciator wire connects the two binding posts on the grooved block. Turn the block until the groove is north and south. Now hold the annunciator wire on the block, parallel to the needle, with the south end of the wire connected to the plus pole of the battery. Close the contact key and record the effect on the needle. Reverse the wire so that the current will flow from north to south over the needle, close the circuit, and note

the effect. Place the wire beneath the block with the current from south to north and record the effect. Reverse the current by reversing the wire, keeping it below the needle, and note the effect.

Then try in succession, one complete turn about the block, two complete turns, three complete turns, and finally as many turns as the wire will permit. In every case record the magnitude of the effect. The circuit must be closed only long enough to obtain the effect; otherwise the current weakens and obscures the effect to be noted. No deflection can be as large as 90°. To get such a value indicates that the compass needle was not on zero before the circuit was closed, and that it should be carefully adjusted and the work repeated. What law expresses the first four effects obtained? What law describes the remaining effects? What uses are made of these facts? Cover up the battery with a cloth and ascertain whether you can determine from the behavior of the compass needle which binding post on the block is connected to the plus pole of the battery. The contact key should be closed no longer than necessary to get the reading of the compass (§ 416).

Form of Tabulation. — Record the results as follows: —

Position of Conductor	Direction of Current	Effect on *N*-end of Needle	Deflection
One wire above needle	South to North	Deflected	. . . . .°
One wire below needle	North to South	Deflected	. . . . .°
One wire above needle	North to South	Deflected	. . . . .°
One wire below needle	South to North	Deflected	. . . . .°
Once around			. . . . .°
Twice around			. . . . .°
Thrice around			. . . . .°
Many around			. . . . .°

EXERCISE LXV. OHM'S LAW

Problem. — *Determine the effect of electromotive force and resistance on the current given out by a battery.*

Apparatus. — Two **dry cells**, new and as nearly alike as possible; two **coils of wire**, each of one ohm resistance; a **contact key**; an **ammeter**, or a tangent galvanometer of low resistance.

Directions. — *First.* Set up a circuit as shown in Fig. 75, with one coil of wire and one cell in circuit. Record the reading of the ammeter.* Place the two cells in circuit, joined in series (§ 437), and record the reading. Since there has been but little increase in the resistance of the circuit in comparison with the total, the resistance may be considered as constant. The electromotive force of the battery has been doubled. Hence, the increased current must be due to that cause. *Second.* Set up the circuit with one cell and a coil of one ohm resistance and record the reading of the ammeter. Now add a second coil of the same size and record the reading. The resistance of the circuit has been doubled, and the current correspondingly reduced. What law expresses these facts?

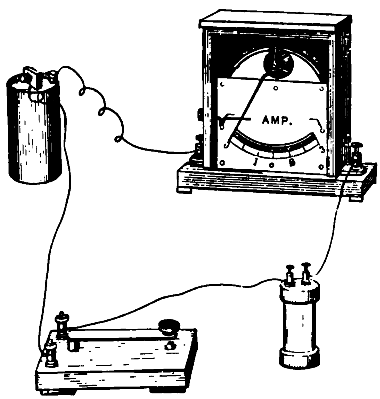


Fig. 75

Form of Tabulation. — Record the results as follows: —

* If a tangent galvanometer is used, note the deflection, and find the tangent from Table VI of the Appendix. The tangent measures the current.

E. M. F.	Resistance	Reading	Result		
			E. M. F.	Resistance	Current
One cell	Battery + 1 ohm	. . . .			
Two cells	Battery + 1 ohm	. . . .	Increased	Constant	Increased
One cell	Battery + 1 ohm	. . . .			
One cell	Battery + 2 ohm	. . . .	Constant	Increased	Diminished

EXERCISE LXVI. ELECTRICAL RESISTANCE

Problem. — *Measure the electrical resistance of three coils of wire differing in length and diameter.*

Apparatus. — A **dry cell**; a **Wheatstone bridge**; a **resistance-box**; a **d'Arsonval galvanometer**; a **contact key**; **wires** for connections; three **spools**, one containing 5 m. of No. 30 German silver wire, one 10 m. of No. 30 German silver wire, and one 5 m. of No. 36 German silver wire.

Directions. — Set up the apparatus as shown in Fig. 76. Introduce one ohm resistance in the box, close the battery key

Fig. 76

with the left hand, and find by trial a place for the sliding key on the wire such that the galvanometer pointer swings to the

right. Then find a second place at which it swings to the left. Between these two positions of the key there is a position at which the galvanometer reading is zero.

The problem now is to find this point. To do this, place the key midway between these two and note the direction of deflection. If, for example, it is to the left, then the place is between the middle and the right-hand point. Then place the key midway between this middle point and the right-hand point and proceed as before. A few trials at most should bring the key to the point of no galvanometer deflection. Record the position of this point on the scale, usually a meter stick; call this R'. $100 - R'$ gives R'', and $x = \frac{RR''}{R'}$ (§ 459). R' and R'' are lengths of a wire. Their ratio is the same as their resistances (Why?) and may be substituted for their resistances in the preceding relation. R is the resistance introduced by the box.

Measure each coil of wire twice and find the average. Compare the ratio of the resistances of the first two coils with that of their lengths. Compare the ratio of the first and last with that of their cross-sectional areas.

It is preferable to secure the balance on the bridge near the middle of the wire. The value given to R can generally be regulated so as to bring this about.

Form of Tabulation. — Record the results as follows: —

Object Measured	R	R'	R''	X
. . . .	. . . .	. . . .	. . . .	. . . .
	. . . .	. . . .	. . . .	. . . .
			Average	. . . . ohm
etc.	etc.	etc.	etc.	etc.

EXERCISE LXVII. THE SHUNT

Problem.—*Measure the resistance of two conductors joined in parallel.*

Apparatus.—The same as in Ex. LXVI.

Directions.—Set up the apparatus as in Ex. LXVI and measure the resistance of each conductor, as coil No. 1 containing 5 m. of No. 30 wire and coil No. 2 containing 10 m. of No. 30 wire. Then connect these coils in parallel (Fig. 77), so that each is a shunt to the other, and measure the resistance. If the first value is r' and the second is r'', then the combined resistance or $r = \frac{r'r''}{r' + r''}$, (§ 457). The nearness of the observed value to the calculated one measures the accuracy of the work.

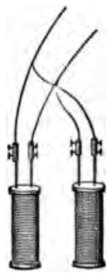


Fig. 77

Form of Tabulation.—Record the results as directed in Ex. LXVI.

EXERCISE LXVIII. ELECTROMOTIVE FORCE

Problem.—*Measure the electromotive force of a battery, and also of two such cells joined (a) in parallel, and (b) in series.*

Apparatus.—A **d'Arsonval galvanometer** of 200 ohms resistance or more*; **a contact key**; **a standard cell**, such as a **Daniell**; two **dry cells**.

Directions.—*First.* Set up a circuit containing the Daniell cell, the galvanometer, and contact key (Fig. 78). Close the key and read the deflection. Substitute one of the dry cells for the Daniell cell, close the circuit, and read the deflection.

*** A galvanometer of less resistance can be used by connecting in series with it a coil of several hundred ohms resistance.**

Now it can be shown that with a large resistance in the circuit, the electromotive force is proportional to the deflection. Hence, $\frac{E}{E'} = \frac{d}{d'}$, where E and E' are the electromotive forces of the Daniell cell and the dry cell respectively, and d and d' are the corresponding deflections of the galvanometer. From this relation $E' = \frac{d'}{d} E$, the value of E being 1.08 volts, E' can be calculated.

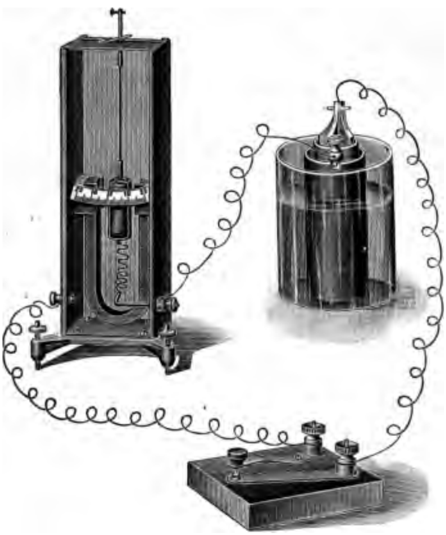


Fig. 78

Second. Connect the two cells in parallel (§ 438) and find their E. M. F. as in the case of a single cell.

Third. Connect the two cells in series and find their E. M. F.

Form of Tabulation. — To be planned by the student.

EXERCISE LXIX. INDUCTION

Problem. — *Study the induction of electromotive forces by magnets.*

Apparatus. — Two **coils** of insulated copper wire, No. 24, one consisting of twenty turns, the other of forty, the hole through each coil being about 3 cm. in diameter; a **d'Arson-**

val galvanometer; two strong **bar magnets**, each about 10 cm. long.

Directions.—Connect the coil of twenty turns of wire to the galvanometer. Thrust quickly into the coil the north pole of the bar magnet (Fig. 79). Note the deflection of the galvanometer. Withdraw the magnet and note the effect. Determine the direction of the current produced by connecting a dry cell to the galvanometer to produce a deflection in the same direction. Try the effect of moving the magnet slowly. Try two bar magnets placed with like poles together. Try the south pole. Repeat all the tests, using the coil of forty turns. Express as laws the conclusions reached.

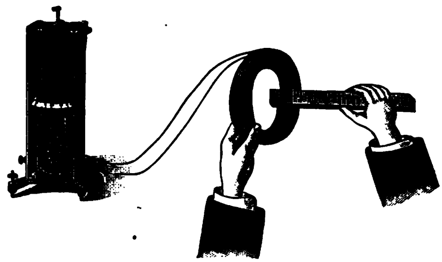


Fig. 79

Form of Tabulation.—Record the observations under the headings, *Conditions* and *Observations.*

EXERCISE LXX. INDUCTION

Problem.—*Study the induction of electromotive forces by electric currrents.*

Apparatus.—The apparatus of Ex. LXIX; a **sheet of iron**; a number of large **iron nails**; a **dry cell**; a **contact key.**

Directions.—Connect in circuit with a dry cell, the coil of twenty turns, and a contact key. Connect the coil of forty turns to the galvanometer. Place one coil on the other and close the battery circuit (Fig. 80). Note the effect on the galvanometer. Note the effect on opening the circuit. Separate

the coils, close the battery circuit, and then bring the coils quickly together. Now quickly separate the coils. Again place one coil on the other, fill the opening with nails, close the circuit, and compare the effect with the first one obtained. Remove the nails, place a piece of sheet iron between the coils, then close the circuit and note the effect. Try a sheet of cardboard. Try a sheet of brass. Try a sheet of zinc. Express as laws the inferences to be drawn from each test made.

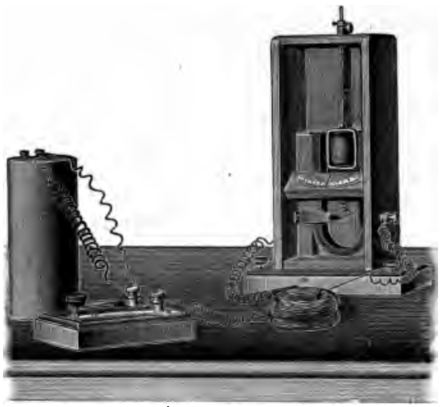


Fig. 80

Form of Tabulation.—Record the observations as in Ex. LXIX.

APPENDIX

Table I. Useful Numbers and Relations

$\pi = 3.1416$	1 in. = 2.54 cm.	1 gal. = 3.785 liter
$\pi^2 = 9.8696$	1 dyne = 0.00102 gm.	= 231 cu. in.
$\frac{1}{\pi} = 0.3183$	1 erg = 0.00102 gm.-cm.	1 at. = 14.71 lb. per sq. in.
	1 ft.-lb. = 0.13825 kgm.-m.	= 1033.3 gm. per cm^2.
$\sqrt{\pi} = 1.7724$	1 H. P. = 33000 ft.-lb. per min.	1 cal. = 4.1894 joules at N. Y.
$\sqrt{2} = 1.4142$	= 7.452×10^9 ergs per min.	g. = 980.19 cm. per sec. per sec. at N. Y.
$\sqrt{3} = 1.7320$	1 km. = 0.62137 mi.	= 32.15 ft. per sec. per. sec.
$\sqrt{5} = 2.2361$	1 joule = 0.7381 ft.-lb.	
$\sqrt{10} = 3.1623$	1 gm. = 15.432 gr.	
$\frac{1}{\sqrt{2}} = 0.7071$		

Table II. Densities of the more Common Substances

Agate	2.5 to 2.7	Ice	0.88 to 0.92
Alcohol, ethyl	0.791	Iron	7.03 to 7.90
Alcohol, methyl	0.810	Lead	11.36 to 11.40
Antimony, cast	6.7	Marble	2.5 to 2.8
Beeswax	0.964	Mercury	13.596
Bismuth, cast	9.7 to 9.9	Nickel	8.3 to 8.9
Brass	8.2 to 8.6	Oil, olive	0.915
Copper	8.8 to 8.95	Paraffin	0.824 to 0.940
Cork	0.18 to 0.24	Platinum	21.2 to 2.17
Glass, crown	2.4 to 2.8	Silver	10.424 to 10.57
Glass, flint	2.9 to 4.5	Steel, wire	7.728
Glycerine	1.26	Tin	7.29 to 7.30
Gold	19.26 to 19.34	Zinc	7.04 to 7.19

Table III. Coefficients of Expansion

Linear

Aluminium	0.00002221	Glass, Jena	0.00000810
Brass	0.00001856	Iron	0.00001220
Copper	0.00001866	Tin	0.00002296
Glass, tube	0.00000833	Zinc	0.00002976

Cubical

Alcohol, ethyl, 0° to 50°,	0.001087	Mercury, 0° to 100°,	0.000181
Alcohol, methyl, 0° to 60°,	0.001248	Oil, olive, 0° to 100°,	0.000803
Glycerine, 0° to 100°,	0.00053	Water, 4° to 100°,	0.000449

Table IV. Pressure of Aqueous Vapor in mm. of Mercury

t° C.	mm.	t° C.	mm.	t° C.	mm.	t° C.	mm.	t° C.	mm.
− 10	2.08	0	4.60	10	9.17	20	17.39	30	31.55
− 9	2.26	1	4.94	11	9.79	21	18.50	35	41.83
− 8	2.46	2	5.30	12	10.46	22	19.66	40	54.91
− 7	2.67	3	5.69	13	11.16	23	20.89	45	71.39
− 6	2.89	4	6.10	14	11.91	24	22.18	50	91.98
− 5	3.13	5	6.53	15	12.70	25	23.55		
− 4	3.39	6	7.00	16	13.54	26	24.99		
− 3	3.66	7	7.49	17	14.42	27	26.51		
− 2	3.96	8	8.02	18	15.36	28	28.10		
− 1	4.27	9	8.57	19	16.35	29	29.78		

Table V. Specific Heats

Alcohol, ethyl	0.615	Iron	0.1123
Alcohol, methyl	0.613	Iron, cast	0.1286
Aluminium	0.212	Lead	0.0314
Antimony	0.0507	Mercury	0.0330
Bismuth	0.0298	Nickel	0.1092
Brass, hard	0.0858	Oil, olive	0.504
Copper	0.0933	Steel	0.118
Glass, thermometer	0.177	Tin	0.0559
Glycerine	0.555	Zinc	0.0935

VI. Table of Natural Sines and Tangents

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

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